

NBS REPORT

8824

MIDDLE AND LOW LATITUDE ATMOSPHERIC EMISSIONS
AND THE IONOSPHERE

A group discussion held at Central Radio Propagation Laboratory
National Bureau of Standards, Boulder, Colorado
April 14-16, 1965



FACILITY FORM 502	<u>N65 87966</u> (ACCESSION NUMBER)	_____ (THRU)
	<u>117</u> (PAGES)	<u>None</u> (CODE)
	<u>CR 64713</u> (NASA CR OR TMX OR AD NUMBER)	_____ (CATEGORY)

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
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Boulder, Colorado

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NATIONAL BUREAU OF STANDARDS REPORT

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NBS REPORT

54000-00-5400900

June 15, 1965

8824

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* Discussion leader

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* Discussion leader

PREFACE

This is the report of the discussion group on "Middle and low latitude atmospheric emissions and the ionosphere" held at the Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colorado - April 14-16, 1965.

The group dedicated its deliberations to the memory of the late Daniel Barbier.

The report which is a brief sketch of those deliberations does not convey the spiritedness of the informal discussions which were the meeting's attraction. No attempt has been made to produce a report complete in every detail. On the assumption that a picture is worth a thousand words this report was constructed to incorporate many of the slides and diagrams shown at the meeting. The diagrams have been supplemented by outlines of the more formal talks. The discussion has been edited to some extent and portions of it have been missed because the tape is unreadable in places.

Though the meeting was attended by a significant number of the interested community, many colleagues, particularly those overseas, could not attend for various reasons. We hope the report will be an information source for absent and future colleagues as well as participants.

We thank all who have helped by supplying the items that appear in this report.

Franklin E. Roach

Keith D. Cole

Co-chairmen

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U.S. Department of Commerce
National Bureau of Standards
Central Radio Propagation Laboratory
Boulder, Colorado
April 14, 1965

Chère Madame Barbier:

On m'a demandé de vous transmettre, au nom d'un grand nombre de mes collègues, l'expression de notre sympathie la plus profonde dans le deuil qui vient de vous frapper. Votre fils était très admiré aux Etats-Unis par tout ceux qui ont eu la chance de travailler avec lui ou de le connaître personnellement.

En particulier, un groupe de plus de cinquante chercheurs scientifiques est actuellement assemblé à Boulder pour une conférence de trois jours pour discuter deux phénomènes découverts par lui. Je fais allusion à des particularités de l'émission de la raie rouge de l'oxygène atomique dans l'atmosphère supérieure de la terre.

En 1957 il attira l'attention sur la relation entre l'émission atmosphérique de cette raie rouge et la structure physique de l'ionosphère, particulièrement dans les tropiques. Ceci résultait de son travail à Tamanrasset et de ses vols en avion de la France à l'Afrique du Sud.

En 1958 il annonçait l'existence d'un arc de type auroral au dessus de la France, à des latitudes très éloignées de celles qui sont normalement associées avec l'activité aurorale.

Je pense que vous serez moins intéressée dans les aspects techniques de ces découvertes que dans le fait que les chercheurs scientifiques qui sont assemblés à la conférence ici à Boulder me demandent de vous faire savoir qu'ils dédicacent cette conférence en son honneur. Nous avions espéré qu'il aurait pu délivrer la lecture principale de la conférence mais, puisque ceci est impossible, nos discussions se sont poursuivies sous l'inspiration que la mémoire de sa dédication à la poursuite de la vérité nous a fournie.

Je suis sûr que vous savez qu'aux sentiments exprimés au nom de mes collègues, je dois ajouter que je suis personnellement bien triste que l'amitié entre Daniel Barbier et moi, qui avait fleuri au cours de quelque dix-sept ans, a maintenant été convertie en une autre dimension.

Bien affectueusement à vous,



Franklin E. Roach

(English translation of letter to Mme. Barbier)

Dear Mme. Barbier,

I have been asked to transmit, on behalf of a large number of my colleagues, deepest sympathy to you in your recent bereavement. Your son was much admired in the United States by many who had the good fortune to work with him or to know him personally.

In particular, a group of more than fifty research workers is now assembled in Boulder for a three-day conference for the discussion of two phenomena discovered by him. I refer to some features of the emission in the earth's upper atmosphere of red light from atomic oxygen.

In 1957 he called attention to the relationship between the red atmospheric emission and the physical structure of the ionosphere especially in the tropics. This was based on his work at Tamanrasset and his flights from France to South Africa.

In 1958 he announced the existence of an auroral-type arc over France, at latitudes very distant from those usually associated with auroral activity.

I presume that you will be less interested in the technical aspects of these discoveries than in the fact that the assembled research workers at the conference here in Boulder wish me to advise you that they are dedicating the proceedings of the conference to his honor. We had hoped that he might give the principal lecture at the conference but, since this is impossible, we shall proceed with the inspiration derived from the memory of his dedication to the pursuit of truth.

You realize, I am sure, that to the sentiments expressed on behalf of my colleagues, I must add that I am personally saddened that the friendship between Daniel Barbier and myself that has flowered over some seventeen years has now been converted into a new dimension.

With affection,

A handwritten signature in cursive script, reading "Franklin E. Roach". The signature is written in dark ink and is positioned above the printed name.

Franklin E. Roach

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+ Invited speaker	c Co-chairman of meeting

TERMINOLOGY USED IN THIS REPORT

- SAR-arc: Stable auroral red arc. Barbier referred to this phenomenon both as "1' arc auroral stable" and "1' arc monochromatique". In the review paper "Stable 6300 A auroral arcs in mid-latitudes" Roach and Roach referred to these arcs as M-arcs.
- TOAE: Tropical oxygen airglow enhancement, called "fingers" by Steiger (see Topic 16).
- FIGURE NUMBER: e.g., Fig. P6.7 would mean the figure 7 of the paper of topic number 6.
Fig. D6.7 would mean the figure 7 of the discussion of topic number 6.
The figures are located at the end of the appropriate discussions, except in a few instances which are appropriately noted in the text.

TOPIC 1

L'ARC AURORAL STABLE

F. E. Roach

The principal phenomenon under discussion in the conference is an arc-like emission of [OI] 6300A discovered by D. Barbier [1958]. The morphological and physical properties of the phenomenon have been described in a review paper by F. E. Roach and J. R. Roach [1963]. Of particular interest is the fact that the arcs have been reported over ranges of the magnetic shell parameter L from about 2 to 4 (see figure Pl.1). Thus the phenomenon as observed occurs at much lower latitudes than the conventional aurora ($L \sim 6$).

They are, however, associated with magnetic disturbances and definitely occur simultaneously with, though apparently geographically discrete from, visual auroras. Thus a complete auroral theory must come to grips with the phenomenon. Apparently the M-arcs (SAR-arcs) involve a quite different excitation mechanism than that required to explain the visual auroras. The prime evidence for this is that the M-arcs correspond to a low excitation level (< 4.2 e.v., 5577A is not sensibly enhanced) whereas the visual aurora displays many spectroscopic features requiring excitations greater than 10 e.v. The purpose of the conference is to probe into the significant physical processes responsible for the interesting phenomenon.

In the tropics (labelled E in figure Pl.1) there is an optical phenomenon associated with the equatorial ionospheric anomaly. The increase of ionization in the ionosphere which occurs some 15° from the magnetic equator results in an increased emission of 6300A. The emission regions may be arc-like but more often they appear as discrete patches. The green line of atomic oxygen, 5577A, is also enhanced indicating that the tropical phenomenon is excitationally different from the M-arc. The program calls for a discussion of the tropical emissions during the last session (Topics 16, 17, 18).

References

- D. Barbier, "L'activité aurorale aux basses latitudes", Ann. de Geophys. 14, 334-355 (1958).
F. E. Roach and J. R. Roach, "Stable 6300A⁰ auroral areas in mid-latitudes", Planet. Space Sci. 11, 523-545 (1963)

Caption

Fig. Pl.1 Zones of Characteristic 6300 A⁰ Activity. The zones labelled 'A' correspond to the centre of the auroral zones; 'M' to the regions within which M arcs have been observed; 'E' to equatorial regions discussed in the last part of this paper.

Discussion of Topic 1 *

Discussion leader: L. R. McGill

Megill called for discussion of crucial observations for the purpose of eliminating theories. He said we should look at (i) the ionosphere in the SAR-arc, (ii) latitudinal extent of SAR-arcs, (iii) twilight observations (intermixing of direct solar radiation and SAR-arc mechanism (iv) scintillation, (v) neutral particle temperature and (vi) the beginning of an arc.

Megill asked, if SAR-arc did occur polewards of Rapid City, was there any probability that they could have been observed. Shepherd said this would be covered in his paper (Topic 6). Hunten said that suitable equipment for regularly observing the SAR-arc is now coming into operation at Saskatoon. Rees said that type A red arcs do occur at high latitudes. They were brighter than the SAR-arc. He believes they have different origins. King reported on 29th July 1959 a red arc was observed at Scott Base (Antarctica) on color film. It was also observed at Cape Hallett on black and white. It was stable and steady for some time then very quickly moved off to the north (equatorwards). Romick said that on the dates on which red arcs were observed by Barbier in France, College showed night-long auroral activity (extremely brilliant). These nights ended in extremely bright red emissions. He wondered whether some of such red emission was not involved in Barbier's observations (allowance made for the difference in longitude).

Cole commented that it was important to know whether the SAR-arc was formed in situ or moves from high latitude to settle at middle latitudes. The SAR-arc appears to be a sink of energy for a ring current (See Topic 7) and as such betrays the position of this ring current in the magnetosphere. Akasofu's neutral hydrogen atom flux for generation of a ring current would cause the in situ formation of a SAR-arc. Cole's theory suggests rather that this ring current develops inwards from the outer magnetosphere and therefore that the SAR-arc should, in its developing stages, move equatorwards from somewhat high latitudes.

Hunten said he had examined the neutral hydrogen atom hypothesis for generating magnetic storms; he considered it inadequate (see also discussion of Topic 2).

Swift suggested that because of the probable physical relationship of the SAR-arc and the ring current, one should look for hydrogen emission in the SAR-arc such as might follow from the flux of 10 kev protons. Rees, prompted by Megill said that one type A red arc which he observed in the auroral zone from College did have hydrogen emissions associated with it.

* Edited from tape by K. D. Cole

Romick asked what is a SAR-arc like at the beginning of the evening. How does it form? Roach said that Barbier reported the "birth" of one SAR-arc. McGill reported that on one occasion he observed SAR-arc mixed up with ordinary aurora and it later moved equatorwards but the situation was very confused.

COMMENTS ON THE RELATION BETWEEN MID-LATITUDE STABLE RED
AURORAL ARCS AND AURORAL DISPLAYS

C. T. Elvey

Charles S. Deehr (MS Thesis, University of Alaska, 1961) indicated that the red auroral arc which passed over Alaska early on the night of 27/28 November 1959 might have been the stable red arc observed at Fritz Peak the same night. A re-examination of all the data available for that night was made to see if a firm relationship can be established. The published data consists of the locations of the stable red auroral arc by F. E. Roach, et al, (J. Geophys. Res., 65, 3575-3580, 1960) and that of Deehr, the former locating the arc from photometric observations at Fritz Peak, Cactus Peak, and Sacramento Peak and the latter locating the auroral arc from meridian scans with a photoelectric photometer at College, Alaska. The other data available in WDC A - Aurora (instrumental) were meridian spectrograms taken at College, Alaska and all-sky camera films taken at College, and Barrow, Alaska; Meanook, Canada; Choteau, Montana and Pullman, Washington. The all-sky camera photographs are useful only when it is possible to identify the red arc by other means such as a photometer, meridian spectrograph, or by comparing all-sky photographs from two locations.

All identified red auroral arcs for the night of November 27/28, 1959 and the stable red arcs when plotted on isoclinic charts were found to be parallel with the isoclines within the accuracy of measurement. To compare the motion of the red arc the crossings of the arc at the magnetic meridian for the several stations were transposed along the isoclines to the magnetic meridian through College and plotted in Fig. D1.1 as ordinates and U.T. as the abscissa. Also plotted in Fig. D1.1 are the north and south boundaries of the hydrogen arc, shown by the dashed line and the continuous line, respectively.

The red auroral arc which moved rapidly across Alaska from north to south reached the center of the hydrogen arc around 0330 UT. All-sky photographs taken at College which are still to be measured indicate that the red arc remains approximately central over the hydrogen arc until 0530 UT. The positions of the stable red arc are shown by the small dots in Fig. D1.1. When the study of this auroral display is completed, it appears that there will be an overlap of approximately an hour and a half with the red auroral arc being about 400 km north of the stable red arc.

Another way to compare the red auroral arcs and the stable red arcs of mid-latitude is through their relationships to magnetic storms. The available list of mid-latitude red arcs seen from Fritz Peak, Colorado and Rapid City, South Dakota when plotted on the hourly D_{st} plots for the IGY (Sugiura, Annals of IGY, Vol. 35) indicate that the arcs occur principally during the recovery phase of an intense magnetic storm or during storms which do not have a sudden and large decrease in the main phase. Furthermore, comparing the hourly motions of the stable red arcs with the hourly D_{st} values shows no relationship as is the case for auroras.

Fig. D 1.2 shows the relationships between the average hourly positions of the auroral features including the mid-latitude stable red arc and the hourly D_{st} (H) for Honolulu for the night of November 27/28, 1965. The upper set of open circles and dashed line is the red auroral arc which passed rapidly across Alaska and the lower set is the mid-latitude stable red arc. The solid circles and continuous line is for the southern edge of the hydrogen arc.

At this point of the investigation it appears that the mid-latitude stable red arcs are not part of the auroral display. Studies of other nights with simultaneous auroras and mid-latitude red stable arcs will be continued.

Added note: The circles dots at the bottom of Fig. D 1.1 are observations of a very faint enhancement of 6300 Å and 6364 Å on the meridian spectrograph at College after the auroral activity in the south had stopped. The enhancement was at zenith distance approximately 80° S and is probably the mid-latitude red arc.

Captions

Fig. D1.1 Positions of the red auroral arc (points above the solid line which is the south edge of the hydrogen arc) and positions of the mid-latitude stable red arc (points below the hydrogen arc). The dashed line is the north edge of the hydrogen arc. (C. T. Elvey)

Fig. D1.2 Positions of auroral features as a function of D_{st} . Top curve is red auroral arc, middle curve (solid) is the south edge of the hydrogen arc, and the bottom curve is the mid-latitude stable red arc. (C. T. Elvey, redrawn by K. D. Cole)

Cole asked Elvey how common was the situation of the 3 arcs occurring together. Elvey said they had seen several events like it. Romick suggests that the hydrogen arc gives the southern limit of the visual auroral disturbances. The hydrogen activity was between normal aurora and the SAR-arc.

A colleague unidentified on the tape asked, "Is the motion of the red aurora attributed to motion in latitude at constant height or to motion upwards due say to heating of the atmosphere?" Elvey said he considered it to be due to the former. Rees confirmed this. Reid asked Roach about the occurrence of SAR-arcs in a mid latitude belt, was there a systematic variation of position or occurrence during the sunspot cycle. Roach replied that statistics existed only on the occurrence not position. Marovich then gave number of occurrences in recent years based on U.S. data (See table immediately below). Reid asked whether we should be looking for them now near the auroral zone.

Some dates when stable auroral red arcs have been observed

Station: Haute Provence, France (See D. Barbier "L'arc auroral stable" Ann. de Geophys. 16, 1, 1960 for further details)

Date (U.T.) 1957: Jan. 21, Sept. 4-23-29, Nov. 26, Dec. 31
 1958: Feb. 11, July 8, Dec. 4
 1959: Jan. 10, Feb. 16, Aug. 6, Sept. 3, Nov. 2, Dec. 5

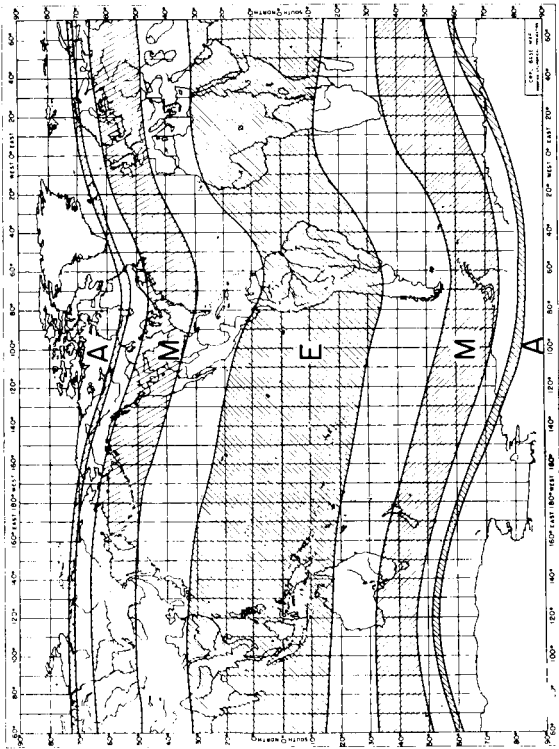
Station: Rapid City, South Dakota, U.S.A. (See E. Marovich and F. E. Roach, J.G.R. 68, 1885, 1963)

Date (L.T.) 1957: Nov. 6/7, Nov. 8/9, Nov. 9/10, Nov. 10/11,
 Nov. 25/26, Nov. 27/28, Nov. 31/Dec. 1,
 Dec. 10/11, Dec. 20/21.
 1958: Jan. 16/17, Jan. 17/18, Mar. 11/12, Apr. 29/30,
 May 27/28, June 9/10, June 28/29, Sept. 5/6,
 Sept. 16/17, Oct. 23/24, Oct. 25/26, Dec. 2/3, Dec. 17/18

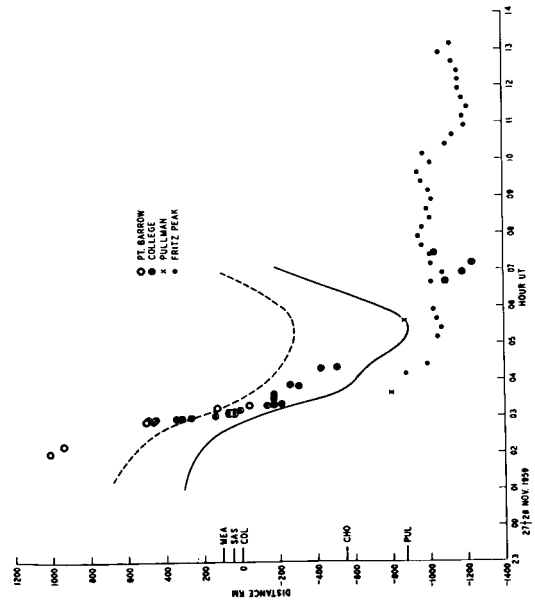
Station: Fritz Peak, Colorado U.S.A. (dates supplied by E. Marovich)

Date 1959: Jan. 9/10, Oct. 31/Nov. 1, Nov. 1/2, Nov. 28, Nov. 30,
 Dec. 1, Dec. 2/3
 1960: April 1/2, April 23/24, April 30/May 1, Oct. 24/25,
 Oct. 25/26, Nov. 12/13, Nov. 13/14, Nov. 15/16
 1961: Jan. 21/22, Aug. 14/15, Sept. 11/12, Sept. 30,
 Nov. 7/8
 1962: None observed. 1963: Sept. 22/23
 1964: None observed.

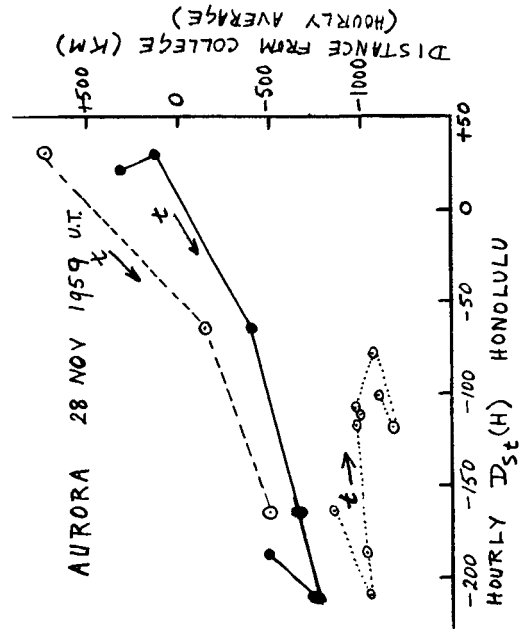
Megill wound up by noting that points he had hoped would be discussed will be discussed in later sessions (See topics 7, 13, 14).



P 1.1



D 1.1



D 1.2

A SURVEY OF MAGNETIC STORMS

E. H. Vestine

The outer boundary of the magnetosphere responds to the solar wind pressure by forming a sort of shock front on the sunward side and extending as a wake. There is an intermediate more or less turbulent medium of plasma encountered in the course of approaching the magnetospheric boundary (Heppner, et al., 1962, 1963; Cahill and Amazeen, 1963). The outer boundary of the magnetosphere has been measured by Ness (Ness, et al., 1964). The pressure applied at the boundary is believed transmitted hydromagnetically to ground level (Dungey, 1955; Parker, 1962).

The study of field lines within the magnetosphere has been considered recently (Midgely and Davis, 1963; Mead, 1964). Near ground level the field is well defined by a recent spherical harmonic analysis of the main field corrected to a spheroidal earth approximation as given by Cain, et al., (1964).

Features of auroral displays related to geomagnetic disturbances have been described by many workers (Chamberlain, 1961; Davis 1962; Akasofu and Chapman, 1964). Ionospheric changes in height and distribution of electrons are often profound (Berkner and Seaton, 1940; Appleton and Piggott, 1952; Martyn, 1953; Ratcliffe and Weeks, 1960; Matsushita, 1964; Obayashi, 1964).

Attempts at explanation of the relation of auroral and ionospheric disturbances to those of geomagnetism have appeared (Frank and Van Allen, 1964; Axford and Hines, 1961; Gold, 1962; Cole, 1963; Akasofu and Chapman, 1964; Fejer, 1963; Tverskoy, 1964; Kern, 1962). In these studies the various phenomena are considered dynamically linked to solar disturbances.

Suggestions have appeared also for explaining trapping conditions for charged particles giving the Van Allen radiation (Singer, 1957). It is not clear how particles get into these radiation configurations nor how electrons become precipitated to produce aurora. A recent ingenious extension of some of Dungey's concepts has been proposed by Petschek. This theory contemplates hooking lines of force in the solar wind to the geomagnetic field lines, some of which are swept into the tail of the earth where they annihilate each other. The energy expended is available for accelerating particles and redirecting them earthward along field lines into the atmosphere (Axford, Petschek, and Siscoe, 1964).

A very interesting feature of disturbance is the rather frequent appearance of small pulsations in magnetic field of period a second or two to many minutes. These are sometimes highly regular and sinusoidal in character and show a number of features compatible with those of hydromagnetic waves.

During auroral displays magnetic pulsations are found which have periods similar to those measured in the auroral illumination (Campbell and Matsushita, 1962). Magnetic pulsations have also been noted with a period of about two seconds in the case of a long thin homogeneous green auroral arc pulsing in intensity over a portion of its length with the same period (Vestine, 1943). Such arcs are noted on occasion about 400 km south of the zone of maximum auroral frequency, but not further north, according to Stormer who observed several near Oslo (Stormer, 1942). These appear to have resembled those observed by Vestine at Meanook, a similar distance south of the average auroral zone. Stormer found their height from photographs was in each case about 200 km.

It seems likely that these very thin long slender arcs (subtending an arc width of about 1/2 to three minutes of arc for a ground observer beneath) are more stable than usual forms of aurora, and behave independently of other auroral displays present. Like the red arc considered by Roach and others the thin green arcs are also well to the south of the auroral zone, and like the red arcs evince no proven morphology associated with the usual auroral displays. Their height of 200 km (in Norway) is also about twice that for ordinary homogeneous auroral arcs. The thin arcs appear to also endure for a considerably longer time than do the arcs at lower levels, but since the total number of observations are few, it may be dangerous to generalize on this matter at this time.

The third adiabatic invariant for trapped radiation must be conserved for such arcs, which requires steady solar wind pressure during the display, or a lower latitude position of the auroral arc.

A Fermi acceleration mechanism can arise and cause dumping of auroral particles, if field irregularities suitably affect trapped particle reflections. The reflecting irregularities along field lines may originate from passage of hydromagnetic waves, transmitted into the magnetosphere by irregularities in the solar wind.

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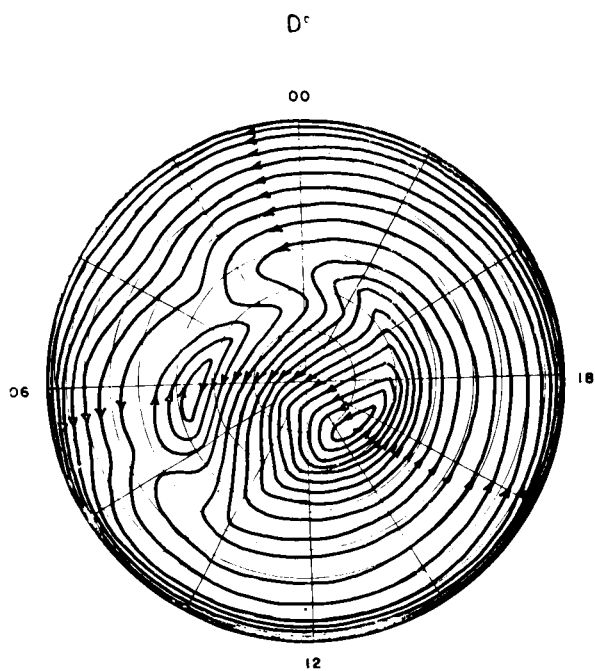
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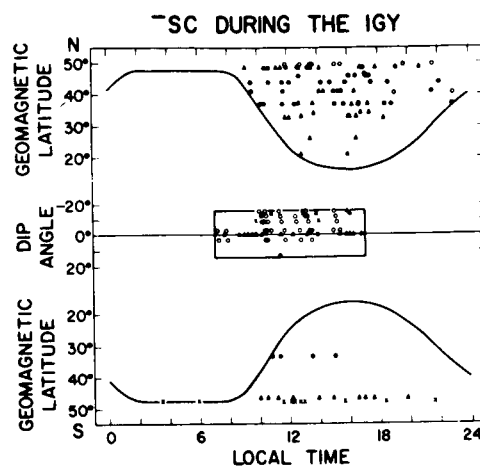
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Captions

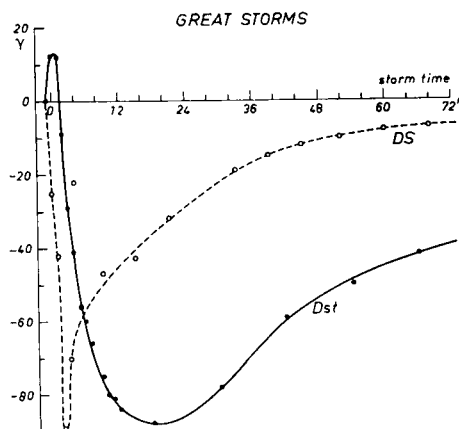
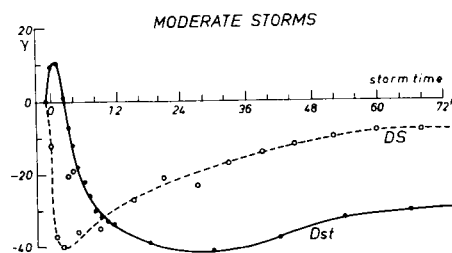
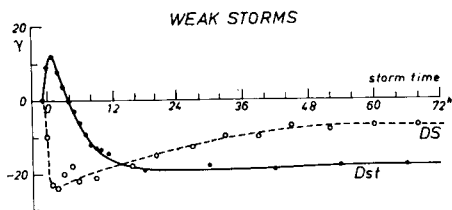
- Fig. P2.1 Average current-system of the D-field for sudden commencements.
- Fig. P2.2 Occurrences of the preceding reverse impulse type of sudden commencement at world-wide IGY stations between geomagnetic latitudes 50°N and 50°S are shown against local time of occurrence and station latitude (the dip angles in the magnetic latitudes at other zones). Solid circles, triangles, crosses, and open circles indicate, respectively, the following four longitude zones: Europe and Africa (geomagnetic 50°E -- 140°E); Asia and Australia (geomagnetic 140°E -- 230°E); northwest America and New Zealand (geomagnetic 230°E -- 320°E); and northeast and south America (geomagnetic 320°E -- 50°E).
- Fig. P2.3 A comparison of the rates of evolution of $\text{Dst}(\text{H})$ and the range ($2c_1$) of $\text{DS}_1(\text{H})$ during the first three days of storms. (Photocopied from Sugiura and Chapman).
- Fig. P2.4 Summary of location of rectified shockwave and magnetopause boundary crossing and comparison with predictions.
- Fig. P2.5 Sketch of the magnetic field configuration in the noon-midnight meridian plane, showing the effect of dragging field lines into the tail by means of tangential stresses at the boundary. The anti-solar neutral line which is perpendicular to the plane is indicated as well as the approximate location of the neutral sheet is meant to indicate the possible existence of a low energy electron flux.
- Fig. P2.6 Polar electrojet system (after Akasofu, Chapman and Meng)
- Fig. P2.7 Positions of homogeneous thin auroral arcs, Meanook, 1933.
- Fig. P2.8 Movement of the 6300 Å arc across the sky for an assumed height of 300 km (left).
- Fig. P2.9 Self-explanatory



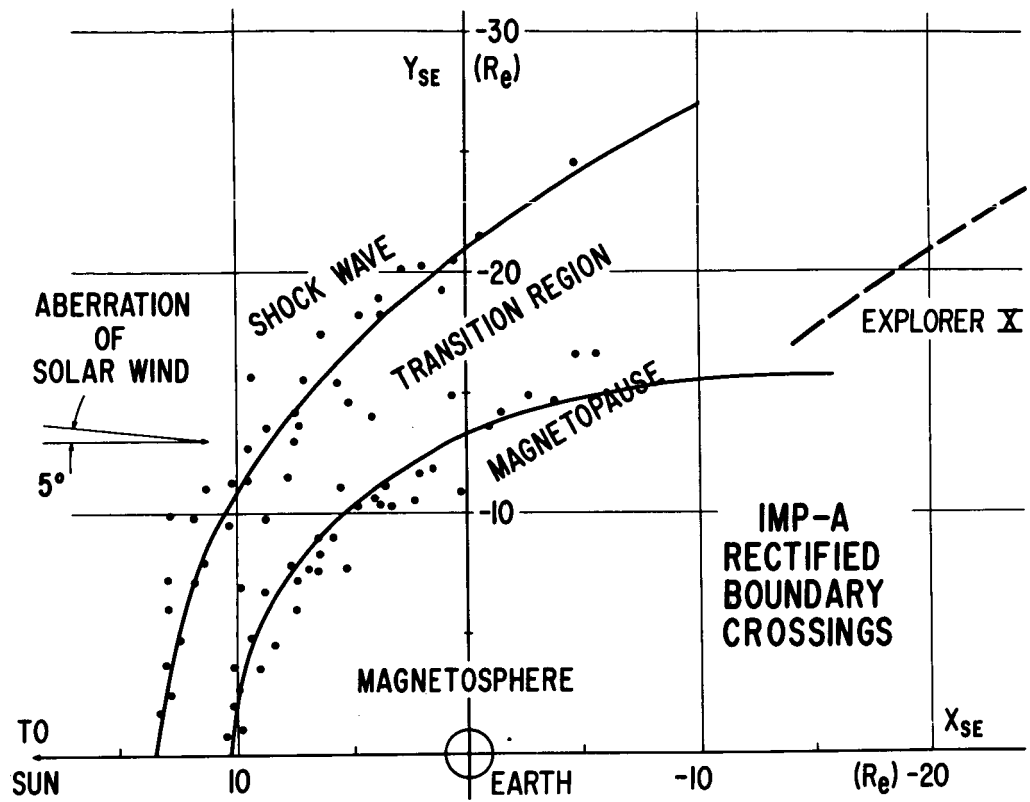
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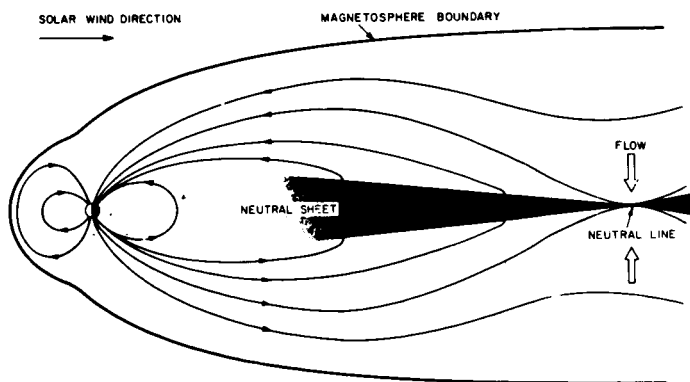
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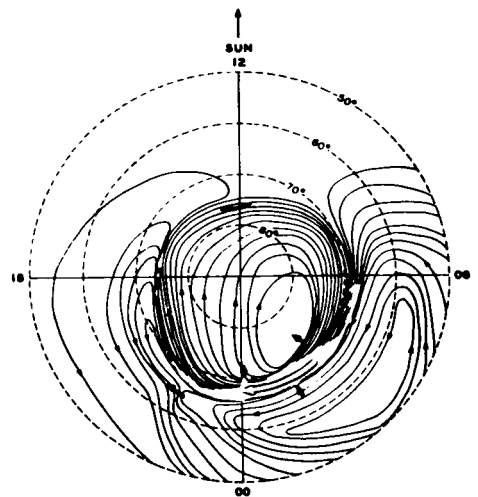
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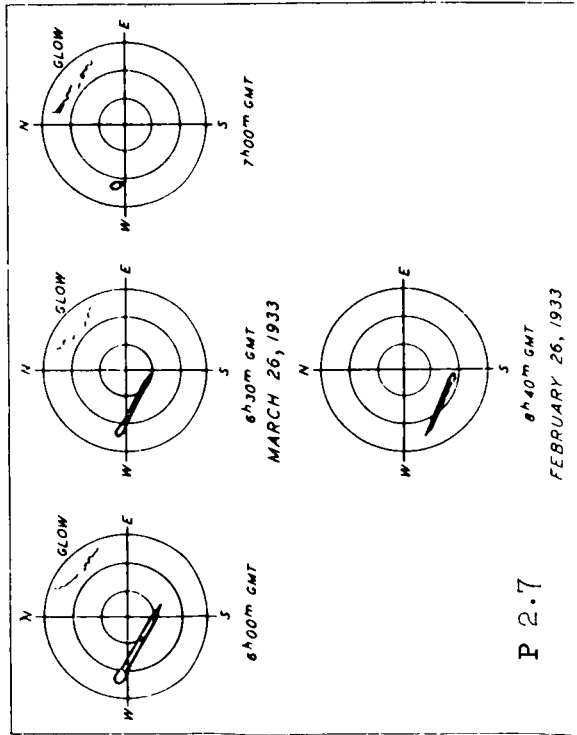
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P 2.5

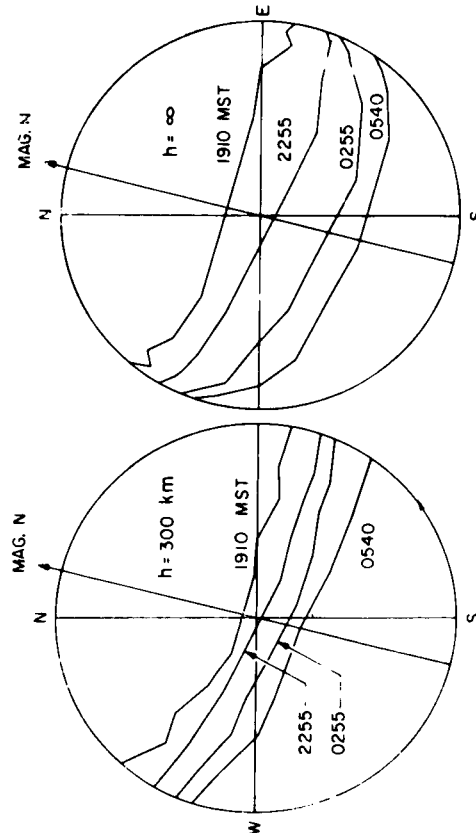
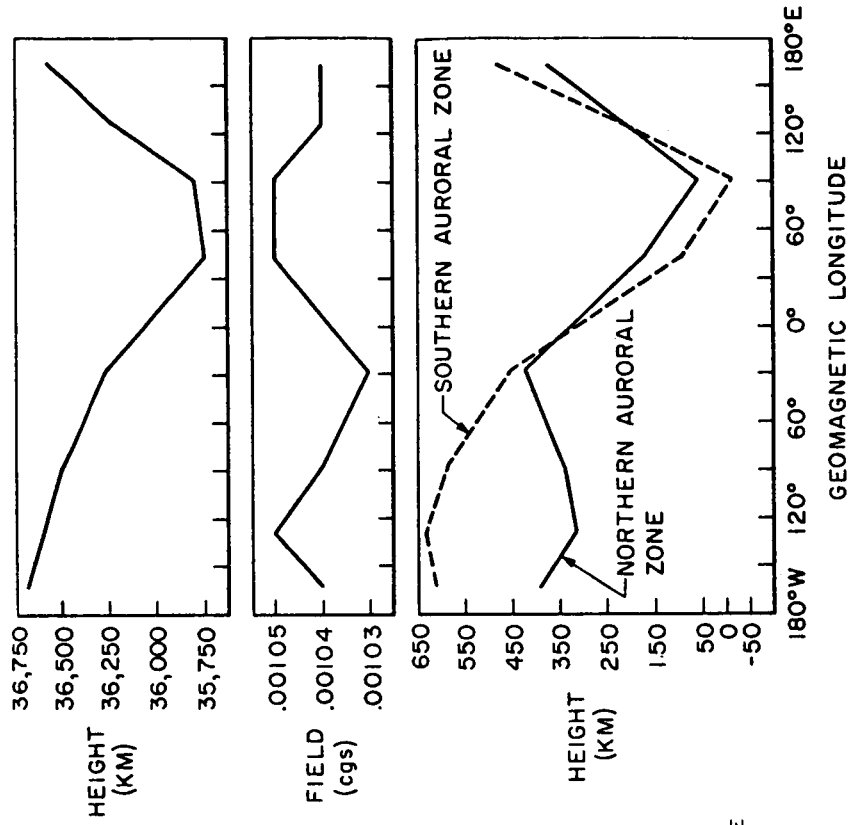


P 2.6



20

HEIGHTS OF LINES OF FORCE AT EQUATOR, FIELD VALUES; ALSO CORRESPONDING MIRROR HEIGHTS OF THESE LINES (LONGITUDES UNSPECIFIED)



P 2.9

P 2.8

Discussion of Topic 2

Discussion leader: G. C. Reid

L shell alignment

Commenting on the alignment of SAR-arcs with L shells (a diagram shown by Roach) Reid said that this signified to him the involvement of trapped particles which, unperturbed, would drift on fixed L shells, provided their energy is above about 10 kev. Below this energy particles become frozen to the magnetic field. This suggested to him that trapped radiation plays a part in SAR-arc formation but there may be a coincidence in which some other agency also gives L shell alignment.

Hanson said this would be consistent with Fejer's method of forming magnetospheric electric fields which would be consistent with the Megill and Carleton theory of SAR-arcs. Carleton confirmed this (see however discussion of topic 3). Cole drew attention to the measurement of a flux of energetic electrons over an SAR-arc, reported by O'Brien, Van Allan, Roach, and Gartlein, which were later rescaled, and asked if there were any other measurements of energetic particles over SAR-arcs. Chamberlain suggested that maybe instabilities produced by the energetic component cause the precipitation of low energy electrons into the F region to produce the SAR-arc. Cole then said that fine luminosity structure within SAR-arcs may betray the presence of the operation of instabilities but that a homogeneous SAR-arc structure may indicate a stable regime. Roach said that as far as photometers tell at the moment SAR-arcs are fairly structureless. He said that the photometer referred to has a 5° field *, structure finer than this would not show. Hunten pointed out that a two-minute lifetime of O'D will allow considerable diffusion ** and one would not expect to see fine structure in the 6300. Indeed, this is the situation observed in normal aurora.

The main phase of storms

Reid outlined Akasofu's ideas on the production of magnetic storm main phases by neutral hydrogen.

Swift showed a slide, due to Akasofu, on the random association of SC with the main phase of a magnetic storm. Examples showed (i) SC without a main phase (ii) an SC followed by a main phase (iii) SC coming in the middle of a main phase (iv) a main phase without an SC. The Forbush decrease has (1.1) only with the SC.

* A SAR-arc at zenith and 300 km wide and height 350 km would subtend an angle of about 50° , i.e. 10 times the field of view of the photometer.

** Rees has calculated a characteristic diffusion distance of about 30 km at 400 km altitude in 100 seconds. This is an order of magnitude smaller than the latitude dimension of a SAR-arc.

Hunten criticised the H atom model of magnetic storms.

ON THE H ATOM MODEL OF MAGNETIC STORMS

D. M. Hunten

Since this model was mentioned by one of the speakers, I feel it worthwhile to point out that it is far from universally accepted, even as a working hypothesis. I shall summarize some of the criticisms that have occurred to Dr. J. C. Brandt and myself; a complete report is now being prepared for publication. Brandt has concerned himself with the suggested emission from the sun and the transit of neutral atoms to the earth; he is convinced that neutral fluxes as large as $10^9 \text{ cm}^{-2} \text{ sec}^{-1}$ are so unlikely as to be not worth serious consideration. Although this flux has been stated to represent only a few percent of the solar wind, it is actually greater than the normally measured proton flux by a factor of 5, and equal to the largest flux observed by the Venus Mariner.

Since I have been concerned with the terrestrial part of the problem, I shall lay more emphasis on this. Briefly, the model proposes that a neutral atom will be converted to a proton by charge exchange high in the atmosphere, at heights between 400 and 700 km. One-third of all the atoms striking the zones between 24° and 67° geomagnetic latitude are injected into trapped orbits. These trapped particles are assumed to have a lifetime of several hours, and can then produce a main phase of 40° , for an incident flux of 10^9 . Actually, an injection efficiency of 30 percent appears to be much too large, and even 3 percent seems optimistic. Moreover, the mirror points of any trapped protons must be at least as low as the initial height of charge exchange, and the lifetime of such protons will be very short, if indeed they can escape from the atmosphere at all in the first place. Finally, even with the very optimistic assumptions only a small magnetic storm was produced, and a tenfold greater flux would be needed to account for a large one.

It can be concluded that an H atom flux of $10^9 \text{ cm}^{-2} \text{ sec}^{-1}$ is too large to be accepted, and that even if it did exist it could not produce a magnetic storm with a main phase as large as 1° .

REPLY *

Syun-Ichi Akasofu
University of Alaska
College, Alaska

Dr. Hunten's comments on my theory consists of two parts; a part due to Dr. Brandt and a part due to himself.

(i) I will reserve comment on Dr. Brandt's opinions since full details have not been given by Dr. Hunten.

It may be of interest to add, however, that bright prominence material seen in solar H_{α} photographs are clouds of neutral hydrogen atoms. We observe them ascending slowly into the corona for more than 30 minutes, in spite of the fact that they suffer from an intense solar radiation and perhaps from an intense bombardment by coronal electrons. We observe also the formation of clouds of H atoms in the corona, the so-called 'condensation'. Therefore, H atoms can not only survive as a group, but can also be formed in the region which has been thought to be most 'dangerous' for them. These phenomena are basic to understand interactions between the solar plasma and the corona [1].

(ii) Consider a very simple situation in which a uni-directional beam of H atoms impings on the magnetosphere. In this case, the reaction ($H \rightarrow p$) occurs in narrow sectors in the morning and evening. Let us assume that the reaction takes place only on the 06^h and 18^h local time meridian planes. The injection efficiency should undoubtedly be 100% and the earth's rotation distributes the particles around the earth. The geometry of the cross-sections will be of two fan-shaped areas (of outer radius $(6370 + 1400)$ km = 7770 km and inner radius $(6370 + 400)$ km = 6770 Km; the subtended angle = $2\pi/3$). Thus, the total cross sectional area is of order 5.7×10^{17} cm². Therefore, for the same flux as I have used in my paper [2] the total energy should be

$$5.7 \times 10^{17} \text{ (cm}^2\text{)} \times 10^9 \text{ (particles/cm}^2\text{)} \times 1.6 \times 10^{-8} \text{ (ergs)} \\ \times 4.3 \times 10^4 \text{ sec} = 3.9 \times 10^{23} \text{ ergs.}$$

The above value may be compared with the corresponding value in my paper (6.9×10^{23} ergs; p. 821-2). Therefore, the injection efficiency should not be too small as Dr. Hunten has suggested.

* Dr. Akasofu was not present at the meeting and supplied this reply subsequently (May 24, 1965).

(iii) The most important point I would like to make here is that the growth of the ring current is independent of the ionized component of the solar plasma flow. Unfortunately, the earlier concept of geomagnetic storms has led us to believe that the growth of the ring current follows an enhancement of the ionized component manifested by the classical storm sudden commencement. However, our recent study shows that the ring current can grow well before the arrival of the ionized component and even without it.

Now, let us estimate the energy introduced to produce the DRL ring current of intensity -200γ on the earth's surface. The belt should contain an energy of order 7.4×10^{22} ergs at any instant. The actual energy introduced into the magnetosphere should be greater than this value, because the simultaneous dissipation process should be taken into account. Further, in earlier estimates of the decay time, it was tacitly assumed that after the maximum intensity of the ring current is attained, the energy introduction ceases, and the belt decays exponentially. It is more reasonable to assume that at the maximum stage of the belt the energy introduction and the dissipation balance each other. We have shown recently that the introduced total energy is at least ten times greater than the above value, namely 9×10^{23} ergs [3]. If we compare this value with the total energy of the solar plasma flow (the number density $10/\text{cm}^3$ and velocity 10^8 cm/sec) impinging on a circular cross-section of radius 3 earth radii for 12 hours, namely 9.1×10^{19} ergs \times 12 hours = 3.9×10^{24} ergs, we can see their difference is about an order of magnitude or less. (This choice of radius 3 earth radii is made because Cahill and Bailey [5] have reported that the major portion of the ring current should be located within a geocentric distance of three earth radii). Therefore, unless there appears a 'hole' in the magnetosphere to 'suck in' all the solar particles, it is not possible to produce the ring current. The existence of the magnetospheric boundary indicates that the earth's magnetic field excludes the solar plasma from the region where the ring current belt is formed. We have to conclude thus that the solar plasma carries 'unseen' energy of the magnitude comparable to the ionized component.

In spite of such a great injection of energy, the growth of the ring current is a rather quiet process. There is no indication of the existence of intense hydromagnetic waves such as those proposed by Dessler, Hanson and Parker [7].

K. D. Cole [6] has recently proposed that electric polarization fields generated by polar electrojets or what he calls 'noise' re-distribute the magnetospheric plasma; the re-distribution is associated with the energization of the plasma. However, our recent study of the growth of both the ring current and polar electrojets indicates that the ring current can be formed well before there are any indications of the growth of polar electrojets [3]. Therefore, his mechanism is not likely to be the primary one.

Summary

As mentioned earlier, the 'unseen' energy for the ring current is not carried by the ionized component; the ring current can grow well before the arrival of the ionized component. Further, the energy flux seems to be the same order of magnitude as that of the ionized component. A possible source is the neutral component of the plasma with flux even greater than that of the ionized component. Blackwell and Ingham [4] have inferred such a high proportion of neutral hydrogen in the plasma flow in order to account for a certain phenomenon related to the zodiacal light. An improved estimate of the effect of the neutral component, both H and He atoms, is now being made.

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EXCITATION MECHANISMS FOR THE OXYGEN RED LINES, 6300-6364,(³P-¹D) IN THE F-REGION OF THE IONOSPHERE

N. P. Carleton

We wish to explain the excitation of the red lines in the night air-glow and in stable auroral arcs. The emission in these cases is observed to come from the 250-450 km region of altitude (where deactivation of the ¹D level should be negligible), and the red lines are much more intense than any other lines or bands (by a factor of 50 or more in the auroral arcs, and by a less well-measured, possibly smaller factor in the air-glow). Granted these facts, we can think of two essentially different excitation mechanisms: (1) an increase in temperature, possibly of the whole atmosphere above 250 km, but more likely of the electrons; and (2) dissociative recombination of O₂⁺ ions and electrons. We shall discuss these in turn.

We may first note that if the atmosphere above 250 km were to be kept in thermal equilibrium, then the population of the ¹D level of oxygen would be sufficient to produce 100 R of red line emission at about 1700°K, and 10 kR at about 2700°K, assuming 10¹⁶ cm⁻² oxygen atoms in the heated region. Since energy is most easily conducted into the atmosphere at these altitudes through the electrons, we may expect that the electrons will be hotter than the other constituents. If we assume the electron distribution to be Maxwellian, but at a temperature T_e, higher than the gas temperature (a very good approximation at these altitudes), then excitation by electron impact upon oxygen atoms will produce 100 R of red lines for T_e ≈ 2700°K, and 10 kR, and 10 kR for T_e ≈ 3800°K. These figures are not very sensitive to the atmospheric model used, because the excitation rate depends so strongly upon temperature. Also, because of the rapid decrease of population with energy in the thermal distribution, the red lines will be very much more intense than other lines of higher excitation potential.

Three mechanisms have been suggested whereby ionospheric electrons may be heated: Cole (1) has demonstrated that transport of plasma in the magnetosphere may produce compression heating, with subsequent conduction of heat downward into the ionosphere. Dalgarno (2) suggests that electrons of 100 ev or less, incident upon the atmosphere, will share most of their energy with the ambient electrons because of the efficiency of Coulomb collisions. Thus we may expect that an influx of such electrons (1 erg cm⁻² sec⁻¹ to excite 15 kR) might excite the red lines strongly, with little direct excitation of other lines. Finally, Megill and Carleton (3) suggest that the passage of electric currents through the ionosphere may heat the electrons to the required temperatures (The required electric fields being of the order of 1 mv cm⁻¹, perpendicular to the magnetic field).

To decide whether any mechanism of electron heating is operating in the airglow and aurora we simply need more measurements of temperatures in the F-region (especially in the auroral arcs). At present it appears that temperatures in ordinary nights are not elevated, and that the airglow is not due to this mechanism. Supposing that hot electrons may be responsible for the auroral arcs, it seems difficult to rule out any of the above heating mechanisms, or to prefer one of them, on present evidence. All probably depend upon similar movements of plasma in the magnetosphere, and hence all may be operating at once. A detailed study of the drift motions of ionization in the F-region would at least distinguish the presence of electric fields.

Dissociative recombination of O_2^+ ions and electrons would seem to be a logical explanation of the red line excitation in the airglow. (N.B.: Dalgarno has pointed out that a spin change is required if recombination of NO^+ and an electron is to yield a 1D oxygen atom, and that this process has presumably a negligible rate.) Assuming that this is the mechanism, McElroy⁽⁴⁾ has made a preliminary estimate of the effective rate coefficient, α^* , such that the product $\alpha^* n(e) n(O_2^+)$ gives the production rate of 1D atoms. He uses measured O_2^+ and electron densities (with some extrapolations) and finds $\alpha^* = 3 \times 10^{-7} \text{ cm}^3 \text{ sec}^{-1}$. This is about equal to the overall O_2^+ recombination coefficient currently deduced from room-temperature measurements.

If this mechanism is to explain the auroral arcs as well, then its rate must somehow be enhanced one-hundred-fold or more to give the observed intensities. Outside of possible increase in the rate due to temperature increase, the enhancement would have to come from an increase in the O_2^+ concentration, since electron densities are observed to be lower than usual in the auroral arcs. An increase in O_2^+ density would mean an essentially comparable fractional increase in O_2 . Increases of total atmospheric density by a factor of ten or so have been measured (by satellite drag) at the same time and roughly the same latitudes where auroral arcs have occurred. It is not out of the question that the required increase in O_2 density could occur, since O_2 is a minor constituent, with a relatively small scale height at these altitudes. Again, a direct measurement of O_2^+ or O_2 concentration in an auroral arc would settle this matter. If the rate could be enhanced by the required amount, then there still remains the problem of supplying the total number of ions which must be consumed in the life of an auroral arc. In a bright arc this is as much as 10^{14} ions per cm^2 , which is in turn greater than the whole electron content of a tube of force of 1 cm^2 cross section in the ionosphere.

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POSSIBLE PROCESSES FOR EXCITATION OF O'D STATE
IN STABLE AURORAL RED ARC (SAR-ARC)

Discussion of Topic 3 *

Discussion Leader: M. H. Rees

Carleton used an effective recombination coefficient for $O_2^+ + e \rightarrow O + O$ of $3 \times 10^{-7} \text{ cm}^3 \text{ sec}^{-1}$, having obtained this value from McElroy. The latter was asked to explain how he arrived at this value. He did so, and the explanation together with a suggested experiment should be obtained from him.

Van Zandt noted that the ratio 6300/5577 in the tropical arcs is about 4:1, that there is excellent spatial correlation between the two emissions, and that they must have originated at the same altitude. Dalgarno asked whether an ionosonde showed increase in electron density and the answer was 'yes' (given by King). McElroy asked why the electron density goes up.

King recanted the dissociative recombination hypothesis for SAR-arc. He re-examined the data of the 1959 arc and concludes that recombination rate is enhanced at a given height by a factor of 15 only, due either to change in particle concentration or rate coefficient, can't distinguish between the two. Roach (the co-author) recanted on different grounds--the tropical arcs are explainable by dissociative recombination with a red to green ratio of 4 so it would be pretty difficult to get the ratio of 80:1 and up noted in the SAR-arcs. For the latter the reaction $NO^+ + e$ had been assumed which cannot give the green line from energy considerations. (It cannot give the red line either, directly, from spin considerations.) Chamberlain suggested that in view of the $\lambda 5200$ observations the above process involving nitrogen be retained at mid-latitudes and that oxygen be left in the tropics, referring to $O_2^+ + e$ giving the green line as well.

McElroy noted that, according to his calculations, if one assumes the dayglow green line to arise from dissociative recombination of O_2^+ with a rate coefficient of $3 \times 10^{-10} \text{ cm}^3 \text{ sec}^{-1}$ one obtains a photon flux which is about ten times larger than the observed value obtained by Lloyd Wallace. Incidentally, the latter's observations indicate the presence of 2 layers, one peaking at 97 km, the other at 170 km with a minimum at about 120 km. He obtained a photon flux of 1.5 kR above 120 km for the green line and 2.5 kR for the red line.

* Edited from tape by M. H. Rees.

Peterson reported that his combined studies of electron density and red line intensity in the tropical red arc yield an efficiency of 0.1 for the yield of $O(^1D)$ atoms from the process $O_2^+ + e \rightarrow O + O$.

On a question by King, Dalgarno felt quite certain that the dissociative recombination of NO^+ can yield nitrogen atoms in the 2D level.

Rees commented that in view of the various arguments which have been presented, is it really worthwhile considering dissociative recombination at all in excitation of the SAR-arc or should one concentrate on the hot electron hypothesis. The only objection to the latter, according to Carleton, is the requirement of a large population of N atoms. But, the observations leading to this result are rather tenuous and should probably not be accepted as being definitive. Hunten suggested that both processes might be operative to which Rees replied that the 4:1 ratio of $\lambda 6300$ to $\lambda 5577$ in the tropical arc is strong evidence of the small role that recombination could play in the SAR-arc.

John Roach mentioned that the strong radio star scintillations associated with SAR-arcs are strong evidence for electron heating.

Carleton noted that the two mechanisms might be coupled through heating and the neutral density increase.

The question was raised (author unknown) as to how one obtains an increase in O_2^+ without getting N_2^+ to which Roach answered that it was nitrogen with which they originally played.

To a question by Dalgarno, Carleton noted that an electron temperature just under $4000^\circ K$ can account for a red arc.

Rees raised the question concerning the nature of the differences between the soft electron hypothesis of Dalgarno and the conduction hypothesis of Cole, noting that the long life time of the SAR-arc would require a rather unusual flux if this were of the auroral type. Carleton claimed that the electric field hypothesis is a limiting case of Dalgarno's soft particle flux, the latter representing the current. The conduction hypothesis is quite different, however.

Walker wanted to know how much energy must be dissipated with the electric field. Megill and Carleton replied that it is about 3×10^{-15} watts/cm³ in the F-region.

Van Zandt obtains about 1 erg/cm² sec dissipated at 200 km, giving 1 kR of red line using an electric current. The energy at E-layer heights would be much larger, perhaps 10 ergs/cm² sec.

Swift noted that these electric currents should be observable by their magnetic effects on the earth. Carleton, however, noted that there is no ionization in the E-region, no current, and therefore no magnetic perturbation.

This led to Cole's presentation of his main criticism of the electric field theory. The electric field with magnitude and direction postulated would result in a positive magnetic bay of 1400 γ at the conjugate region. The electric field is carried to both hemispheres, one of which is in the daytime. The question of closure of the electrojet was not treated by McGill and Carleton nor taken up by Cole.

On instigation by McGill, Cole also presented his criticism concerning the decay of the electric field. Viscosity effects are important here, and these depend on the electron density profile which is as yet not known uniquely.

McGill and Cole then had an exchange concerning the energy input mechanisms, sunlit conditions, and the lifetime of the arc. Observationally, it is difficult to distinguish a twilight effect in the SAR-arc from the normal twilight enhancement of $\lambda 6300$.

Roach closed the session by remarking that the goal of the meeting was to get all theorists to recant objectively. Barbier was right after all--too bad for the theorist!

MONOCHROMATIC MORPHOLOGY OF THE AURORA

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INTRODUCTION

The importance of studying the aurora in terms of the various emission features is obvious. Since the emission is produced by the atomic and molecular constituents of the upper atmosphere when excited by some process, their relative spatial distributions will allow the deduction of excitation mechanisms, atmospheric composition, energy, flux and species of the primary particle etc. The latitudinal behavior will perhaps clarify the magnetospheric origin of the exciting particles and the overall theory of auroral production.

Although the inherent possibilities for discussion in the data which will be presented are numerous I have selected three main topics which are of interest in themselves and yet bear strongly on one subject of this discussion group, i.e. mid-latitude red arcs.

These topics are:

- A. The decline in the relative intensity of the 6300 OI auroral emission with the decline in the sunspot number.
- B. The latitudinal motion of the aurora with emphasis on the fact that the hydrogen arc delineates the southern limit of an auroral disturbance.
- C. The large spatial extent and high ratio of red to green oxygen emission observed at high altitudes in an auroral arc.

The Decline in the Relative Intensity of the 6300 [OI] Emission

Routine magnetic zenith observations of the auroral activity at College, Alaska, have been made using a highspeed flint glass prism spectrograph. These data have been recorded since 1957 and allow the determination of the variation of the activity throughout the present solar cycle. Fig. P4.1 illustrates the type of spectra obtained with this instrument. The continuous motion of the plate holder provides a time resolved spectrum in which the time resolution and equivalent exposure are approximately one hour. The spectrum shown in Fig. P4.1 is that taken on February 11, UT 1958. The greatly overexposed red 6300-6364 [OI] lines attest to the great redness of the visual display. From these daily spectra an activity index has been set-up on a scale from 1 to 9.

1 corresponds to the lack of, or just barely visible, 5577 [OI] emission all night long. 9 corresponds to the type of event characterized in Fig. P4.1. Fig. P4.2 shows the plot of the monthly averages of these index numbers over the years 1957 through the spring of 1965. Also included are activity indices for the H alpha emission and the Sodium (Na) emission. There appears to be a double cycle in the auroral activity during this solar cycle. The second cycle begins in the fall of 1962 and perhaps coincidentally only one mid-latitude red arc was detected after that time and it was a weak display in September 1963.

The Na and H alpha curves are included to show the dependence of these night time emissions on the general auroral activity. Fig. P4.3 is an attempt to illustrate the changing characteristics of the auroral spectra throughout the sunspot cycle. One spectrum from each season has been selected to illustrate the typical spectrum for that year. The most noticeable change has been that in the intensity of the 6300-6364 [OI] emission. The relative intensity between 6300 [OI] and 5577 [OI] is easily seen to decrease from 1957 to 1965. This observation, though unique in its being based solely on the 6300 [OI] emission is not unexpected. It has long been noted that high latitude aurora and long extended rays are absent during the minimum of the sunspot cycle.

In summary this evidence illustrates the decline in the intensity of the 6300 [OI] emission without subsequent decline in many of the other auroral emissions especially 5577 [OI] and the 1st negative system of N_2^+ . Thus it appears certain that some ingredient in the mechanism responsible for the 6300 [OI] emission has become scarce during the decline in the solar cycle. The lack of observations of mid-latitude red arcs may also be due to this factor.

The Latitudinal Motion of the Aurora

The general latitudinal behavior of the aurora may in some way be connected to the appearance of the mid-latitude red arcs other than through strictly magnetic dependence. The systematic progression of the hydrogen arc is ably reported in the work of Rees, Belon and Romick; Montbriand and Vallance Jones; Stoffregen and Derblom, etc. Fig. P4.4a and 4b show the southern progression of the peak intensity of the H alpha emission in the early part of the evening and its subsequent withdrawal northward in the morning. The movie shown during the conference illustrated this north-south progression on another night through observations made with rapid meridian scanning interference filter photometers monitoring H beta, 5577 [OI] and 6300 [OI]. The hydrogen arc is shown to delineate the most southernly extension of the nightly disturbance. Its relationship to mid latitude red arcs is certainly of prime interest. All mid-latitude red arcs have been seen southward of active auroral displays, consequently the possibility exists that they are either part of the hydrogen arc, or are directly related to it through the basic excitation mechanism for the 6300 [OI] emission. Certainly the latitudinal extent of the two phenomena are quite similar. The study of this relationship should be an important part of any future research program concerning these phenomena.

The Spatial Extent of the 6300 [OI] Emission

Using rapid scanning interference filter photometers at two or more stations aligned along the geomagnetic meridian the volume distribution of auroral luminosity in various emissions may be obtained. From such an observational program in 1960, (see, Romick, G. J. and A. E. Belon, 1964) a single rayed arc was selected for detailed analysis. Fig. P4.5 shows the Intensity vs Zenith angle curves for the three emissions 3914 (N_2^+) 5577 [OI] and 6300 [OI] at two stations College and Ft. Yukon, Alaska. By combining the data obtained at the two stations for only the discrete arc the maximum boundaries for the various emission regions can be plotted as in Fig. P4.6. The striking difference in the size of these emission regions is one of the important features found in this investigation. Assuming that the emission originated in a thin sheet (which it obviously does not) one can deduce a height profile of the normalized volume emission rate for these emissions as in Fig. P4.7. The similarity of the 3914 (N_2^+) and 5577 [OI] emissions are expected, the large 6300 emission region though expected is not easily explained. Through iterative type analysis the widths of the regions were taken into consideration and horizontal distributions as well as correct vertical distributions determined for both 5577 [OI] and 3914 (N_2^+) Figs. P4.8, 9. The bulk of these emissions occur in a latitudinal strip 6-10 km wide. In the case of 6300 [OI] it was not possible to combine the two station data because of the combined effects of the long life time of the D state, pre-history of the arc and the extremely broad emission region. However, from the College Intensity vs Zenith angle curves we can discuss the general emission region. Fig. P4.10 shows the Intensity vs Zenith angle curves for the 6300 [OI] and 5577 [OI] emissions as well as their ratio I_r/I_g . It is obvious that the maximum ratio of these emissions is greater than 100. This is the same large ratio as those reported for mid-latitude red arcs. The intensity peak in the 6300 [OI] emission is seen to occur above 300 km, yet the maximum boundary for the 5577 [OI] emission region (see Fig. P4.6) does not extend much past that height. Consequently the volume emission ratio of 6300 [OI] to 5577 [OI] must be exceedingly large above 300 km. Combine this height variation with the large width differences in the two emissions and the ratios may get even larger. One cannot help but recognize from this information that the excitation mechanism for 6300 [OI] must be one dependent on particle precipitation because of its association with the auroral form, but not on direct excitation through incident or secondary active particles as in the case of 5577 [OI] and 3914 [OI].

Conclusion

In summarizing the available evidence in relation to the 6300 [OI] emission these facts stand out:

- A. The intensity of the auroral 6300 [OI] emission and the occurrence of mid-latitude red arcs have both decreased with the decline in the sun spot cycle.

- B. The hydrogen arc delineates the southern limit of the active auroral display and mid-latitude red arcs when seen are always south of active aurora.
- C. The spatial distribution both in height and latitude of auroral 6300 [OI] emission strongly resembles that of mid-latitude red arcs.

It would seem that at least the excitation agent for the production of 6300 [OI] whether it be through heating, electric fields, incoming protons or electrons and a changing atmospheric composition must be the same for both the mid-latitude red arcs and the 6300 [OI] emission from the aurora.

The work reported herein has been sponsored by grants from the National Science Foundation through the Atmospheric Sciences Section.

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Captions

- Fig. P4.1 Huet Spectrograph Plate - Feb. 11, UT, 1958. Illustrates the tremendous enhancement of the 6300-6364 [OI] emission responsible for the observed great red aurora.
- Fig. P4.2 Auroral activity index for College, Alaska for the years 1957-1965. Curve A represents the monthly averages of the auroral activity indices. Curves Ha and Na show similar indices for the hydrogen H alpha emission and the nighttime sodium (Na) emission.
- Fig. P4.3 Zenith Spectra at College, Alaska illustrating the decline in the relative intensity of the 6300 OI emission with the decline in the solar sunspot cycle.
- Fig. P4.4 Meridian Spectra (15 minute exposures) at College, Alaska
a, b illustrating the North-South-North progression of the Hydrogen emission during one night.

- Fig. P4.5 The I vs Z curves and background connections (dashed line) for the three auroral emissions 3914A (N_2^+) and 5577A-6300A OI for both College and Fort Yukon at 2100 West Meridian Time on February 26, 1960.
- Fig. P4.6 Geometrical determination of the location of the auroral form showing the height of maximum liminosity, and the best fit boundaries for each of the three emission regions.
- Fig. P4.7 Normalized vertical profiles of the volume emission rate in 6300A, 5577A OI and 3914 (N_2^+) obtained under the thin sheet approximation.
- Fig. P4.8 The effect of path length on the determination of the vertical profiles of the 5577A OI , dashed curve, and 3914A (N_2^+), solid curve, volume emission rates.
- Fig. P4.9 Horizontal profiles of the 5577A OI , dashed curve, and the 3914A (N_2^+), solid curve, volume emission rates. The two curves for each emission illustrate the effect of adding a broad triangular function to a narrow gaussian function in the horizontal distribution.
- Fig. P4.10 I vs Z curves of the 6300A and 5577A OI emissions from College along with the intensity ratio $I_r(6300A)/I_g(5577A)$ vs a function of zenith angle at College.

TOPIC 5

EXCITATION OF OI $\lambda 6300$

M. H. Rees

Romick has reported that the OI $\lambda 6300$ radiation is emitted principally upwards of 250 km in an auroral arc and that the width of the region of $\lambda 6300$ radiation is several times that of the $N_2^+ \lambda 3914$ and OI $\lambda 5577$ width. Some calculations were carried out to rationalize these observations.

With regard to the increased width of the red emission in the arc it can be shown that lateral diffusion of the excited $O(^1D)$ atoms increases the width (or latitudinal extent) of the $\lambda 6300$ profile by more than a factor of two over the ionization width profile. The effect is altitude dependent: quenching decreases with height and diffusion increases with height. Thus, if this process is to account for the observations the altitude of $\lambda 6300$ emission must extend at least to 400 km.

Romick's height profile for $\lambda 6300$ cannot be explained entirely in terms of collisional deactivation even if a rate coefficient as high as $10^{-10} \text{cm}^3 \text{sec}^{-1}$ is invoked. (From analysis of some old work by Kvifte and Vegard it was deduced by Hunten that the rate coefficient for deactivation of $\text{O}(^1\text{D})$ by O_2 is very small, about $3 \times 10^{-15} \text{cm}^3 \text{sec}^{-1}$. Thus N_2 may be the deactivating species, though this involves nonconservation of spin). In any case, the quenching rate I have assumed is high, and the observations simply cannot be explained entirely on the basis of the relative excitation rates of ^1S and ^1D levels by the secondary electrons produced in auroral ionization. Calculations have been carried out to show that energy deposited in the electron gas is conducted upwards from the 150 to 200 km region to the 350 km level, and downwards to this level from above. Some results presented at the meeting were erroneous due to neglect in applying a lower boundary condition to the solution of the continuity equation. This error resulted in unreasonably high electron temperatures and incorrect temperature gradients and heat flow. The error has since been corrected with the conclusions stated above. Numerical details are still in the course of computations; suffice it to state that the observed altitude profile of $\lambda 6300$ in the aurora can most likely be explained in terms of electron heat conduction.

Ionization is absent in SARARCs and the heat input most likely originates solely from above. If an electron flux of sufficiently low energy is invoked the proper conditions of electron density and temperature may be created above 350 km to cause a large and continuous flow of energy downward along the field lines via the electron gas. This is, of course, Cole's theory for SARARC and the reader is referred to his presentation (topic 7).

Discussion of Topics 4 and 5 *

Discussion leader: G. J. Romick

King asked about the difference between the $\lambda 3914$ height luminosity profile and the $\lambda 5577$ profile.

Romick replied that a background luminosity had to be assumed in 3914 in order to reproduce the intensity versus zenith angle traces from the two observing stations. He believes that the difference in the horizontal profiles of these two emissions is real.

Hunten pointed out that one has to be exceedingly careful in correcting for rayleigh scattering, particularly at the short wavelength and that multiple scattering might produce the difference.

* Edited from the tape by M. H. Rees

Romick tested for this possibility by subtracting the $\lambda 5577$ profile from the 3914 profile and noting the shape of the remainder. It was not symmetric as one would expect from scattering, but asymmetric as expected from the effect of path length difference through different volume emission regions.

Chamberlain inquired whether the variation in the ratio of $\lambda 6300$ to 5577 can be attributed entirely to a height effect, or whether some other cause must be sought, particularly with respect to the sunspot cycle variation pointed out during Romick's talk.

A definitive answer could not be given by Romick but he pointed out that during the minimum sunspot period long, extended rays are also not observed which would be consistent with a decrease in the $\lambda 6300$ emission, both originating at high altitude. This seems to indicate that the atmosphere plays an important part. He will compare the IGY data with current data to see whether a systematic change exists.

Carleton commented that, in addition to the electron density profile, neutral density profile, and the electron energy spectrum, there are electric fields which cause the electron temperature in the F region to rise to an interesting range (causing excitation of $O(^1D)$ by electron impact). Such electric fields must exist because a current flows. So, there should be a term in the red line intensity which is proportional to the height integrated product of electron density, atomic oxygen density and an exponentially varying current which arises from the electric field. It would be of interest to measure these three quantities simultaneously. The effect of the electric field may, however, be entirely masked by the emission arising from particle bombardment.

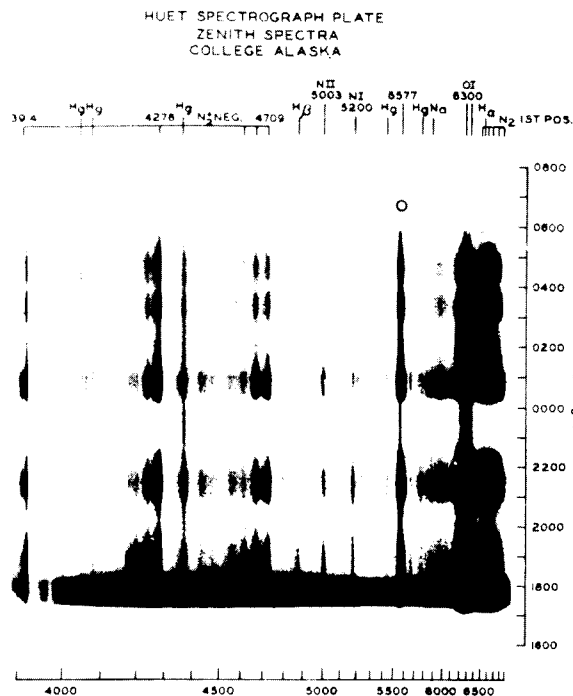
Swift noted that recently some brilliant $\lambda 5577$ aurora has been seen which was accompanied by relatively weak magnetic bays whereas during the IGY similar aurora was associated with much stronger bays.

Cole endorsed Carleton's point on the importance of electric fields above auroral electrojets, but did not think these were applicable to mid-latitude SARARCs.

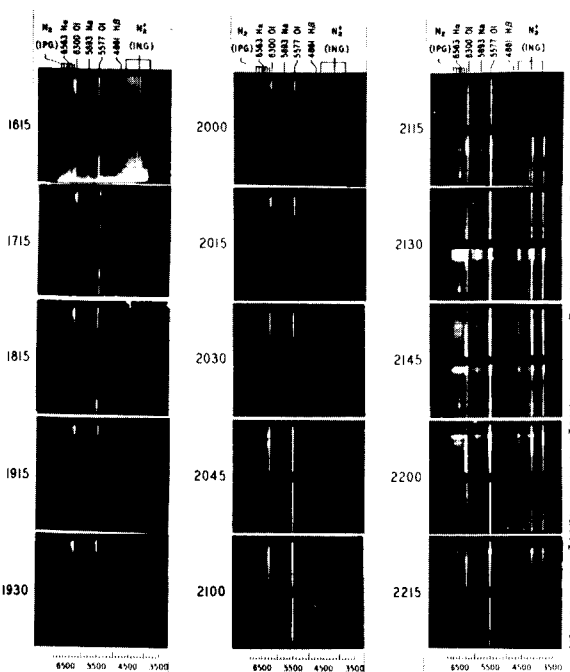
Cole brought up the question as to whether the observed variation in intensity of emission lines is really a solar cycle effect rather than simply reflecting a variation in K_p . Specifically, would two storms associated with the same K_p have different intensity distributions depending on the time of occurrence during the solar cycle?

Romick replied that it is very difficult to compare auroral displays, no two seem to be alike, and establish criteria of similarity and differences. He has not made a careful study relating the spectral distribution to K_p . The only definitely established relationship with K_p is the equatorward limit of the aurora. The equatorward extent of the region of hydrogen emission is very pertinent and it may be that the hydrogen belt is related to excitation of the SARARC.

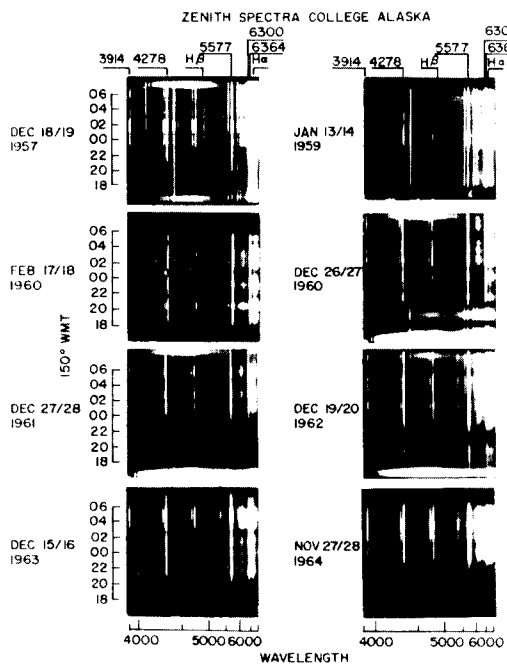
In closing, Chamberlain suggested that perhaps the theorists are working the wrong way around. For example, there is no problem in explaining the difference between the $\lambda 3914$ and $\lambda 6300$ emissions, in fact there may be four or five possibilities depending on the approach that is taken. It is up to the theorist to suggest crucial observations to differentiate among these possibilities.



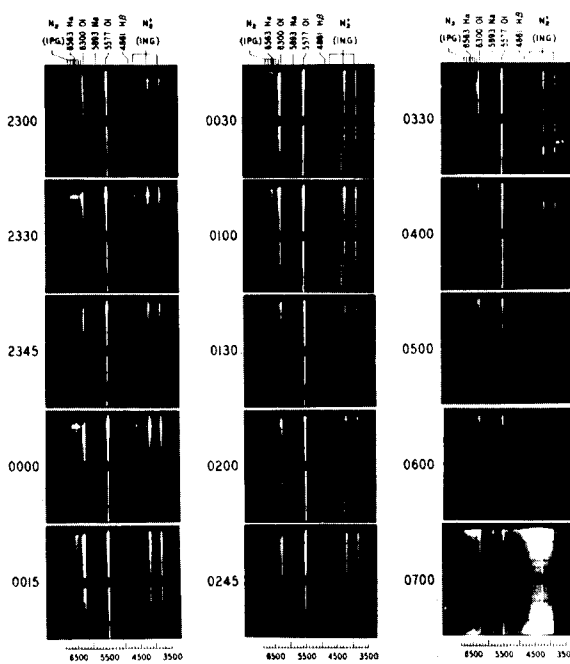
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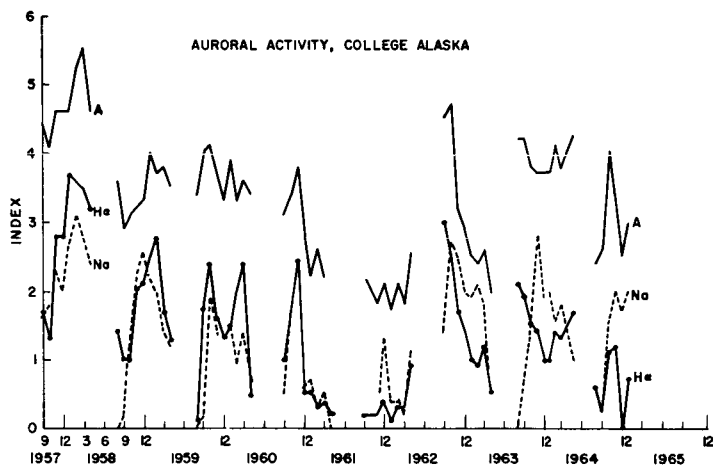
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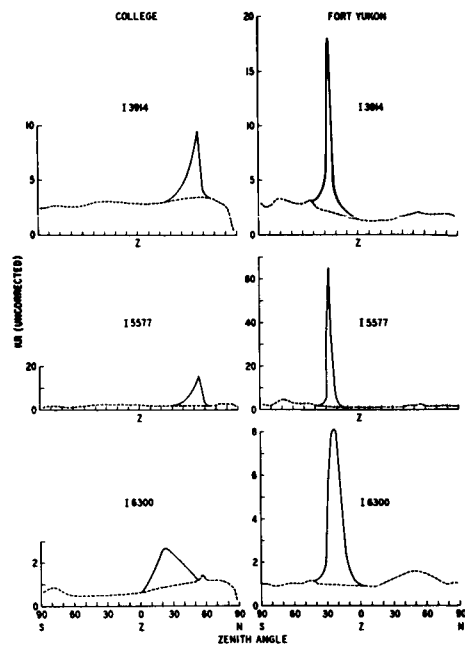
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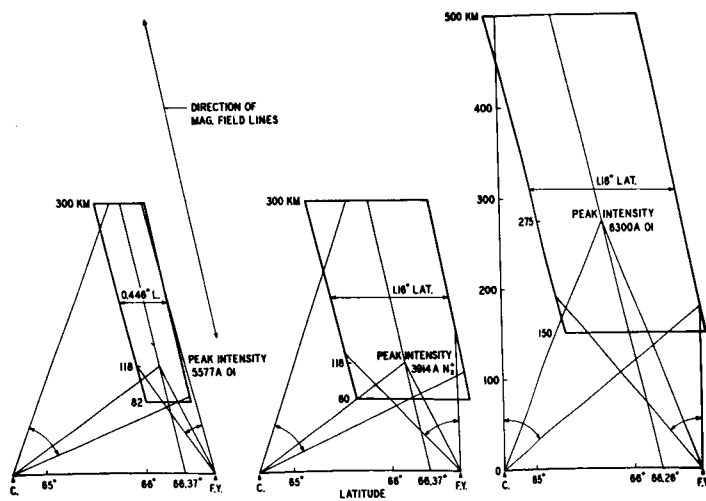
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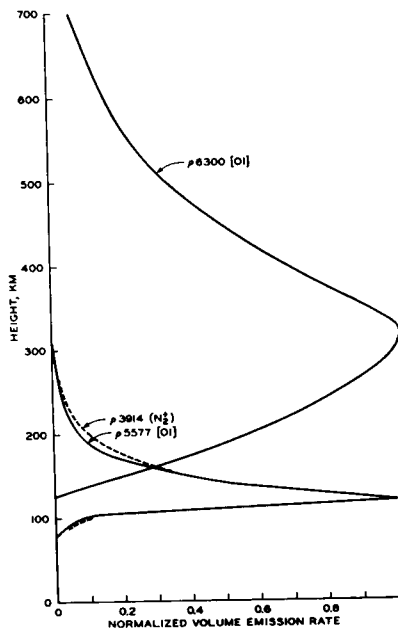
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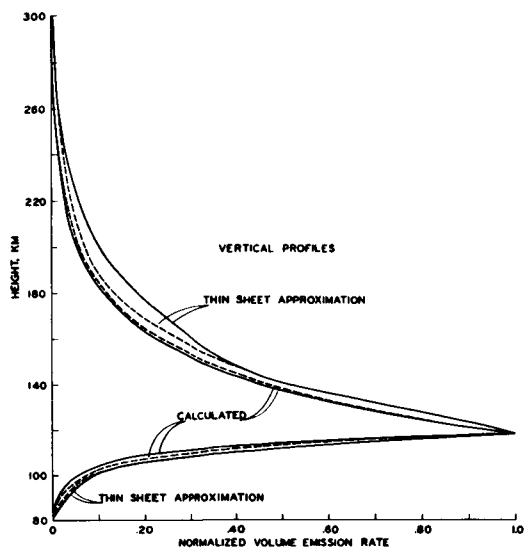
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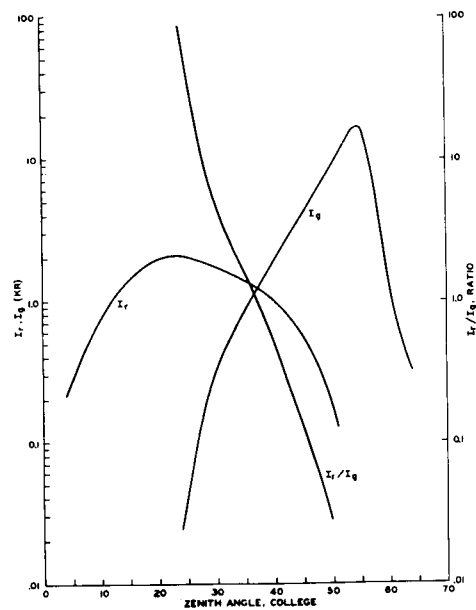
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P 4.7

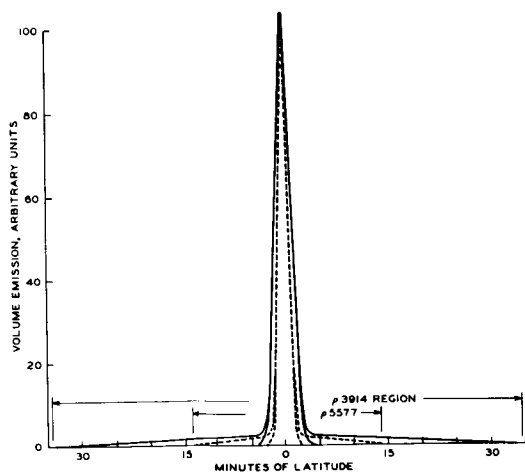


P 4.8

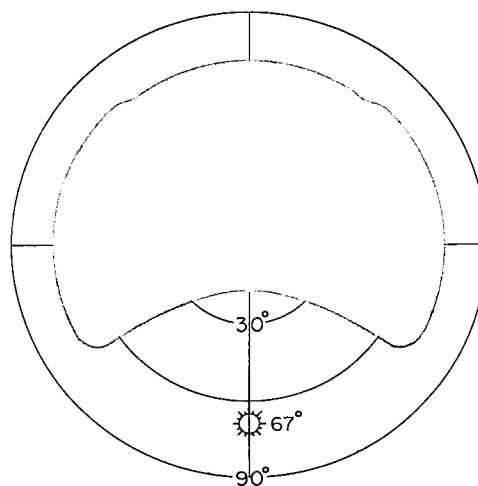


P 4.10

RAYLEIGH ATMOSPHERE MINIMUM INTENSITY = .015



P 4.9



POLARIZATION > 35%

INTENSITY < .06

SUN AT 67°

P 9.10

TOPIC 6

STORM-TIME VARIATION OF AURORA IN THE CIS-AURORAL REGION, PARTICULARLY THE 6300A LINE

G. G. Shepherd, University of Saskatchewan,
Saskatoon, Canada

Relatively little work has been done on red line morphology, perhaps because of the tendency to assume that red line emission is closely related to normal aurora. Unfortunately, this makes it impossible, from existing data, to make a proper correlation between red line emission in aurora and SAR-arcs. An attempt is made here to interpret the small amount of data available from Saskatoon. It is clear that more extensive studies, such as have been carried out on the hydrogen lines, could be of great value.

General Morphology:

The analysis of IGY all-sky camera film has led to two recent morphological models of auroral behavior; one by Davis⁽¹⁾ and one by Akasofu⁽²⁾. The former is based on a fixed excitation pattern, locked by geomagnetic time, under which the earth rotates. The latter describes the development of a "sub-storm", which can develop at any universal time, but does so about the solar midnight position. All subsequent behavior is described with reference to this place and time.

Little morphological work has been done at Saskatoon (60°N geomagnetic), but the general behavior can be said to agree with Akasofu's model. Aurora is seen at Saskatoon only after expansion of forms from the auroral zone. The southward limit of aurora does seem to indicate the activity of the storm.

Recently, however, John Black⁽³⁾ at Saskatoon has made a study of the auroral distribution on quiet nights during the IGY. Auroral forms were observed to move southward in the early evening, and then stabilize at the southward limit; sometimes remaining there the remainder of the night, or sometimes retreating to the north in the morning. These forms are not completely quiet, in that they undulate about a relatively stationary centre of gravity. Nevertheless, if they were observed with a scanning photometer they would probably appear stable -- perhaps as stable as SAR-arc.

Problems in Red Line Morphology:

Chamberlain⁽⁴⁾ first made it clear that a problem exists in obtaining large red/green (6300A/ 5577) ratios in aurora, and Seaton⁽⁵⁾ subse-

quently made calculations on the excitation rates involved. Since that time it has been shown from dayglow observations that the deactivation rate coefficient for the red line is very large, accentuating the problem even more. Red/green ratios determined by single-station photometry lead to ridiculous conclusions. Romick(6) has used two-station photometry to obtain a ratio of .03 at 125 km and 90 at 300 km. These imply ratios of the excitation rates to be 170, and 1800 respectively. Either the exciting mechanism greatly favors the 'D state over the 'S, or else measurements showing red line emission from altitudes below 250 km or so are not correct.

But more difficult cases to explain can be cited:

- (i) Manring and Pettit(7): red/green ratio of 10^4 for aurora at Sacramento Peak, Feb. 10/11, 1958 (more monochromatic than a SAR-arc).
- (ii) Størmer(8): report of green rays changing to red along the entire length, measured from 110 to 500 km.
- (iii) Størmer(8): red rays having measured heights from 130 to 500 km.

In other words, such aurora requires an excitation mechanism as specialized as those for SAR-arcs.

Comparison of Aurora at Saskatoon (60.2°N geomag.) and Regina (59.2°N geomag.) with Presence of SAR-arcs at Rapid City during IGY:

This comparison has been prepared by John Black. It is given in terms of "events", an event being the name given to a rapid southward spreading of aurora and its subsequent recession. During IGY, 22 nights were listed as having SAR-arcs at Rapid City. Of these, 13 were reasonably clear at Saskatoon and Regina. All of these nights showed aurora, whereas of 186 nights during IGY, only 52% showed distinct aurora at these stations. The following table gives information on the southward extent for the 13 nights:

Southern Limit of Distinct Forms	% of Nights having	
	SAR-arcs + aurora	Aurora only
	--	--
North of Saskatoon	38	66
Between Saskatoon and Regina	31	14
South of Regina	31	20

A detailed presentation of the distribution of aurora on these nights is shown in Figs. P6.1, P6.5. From the data given above, and the Figures, it can be concluded that when SAR-arcs exist, ordinary aurora exists nearby, during part of the night, at least.

This has a pronounced effect on observations as made from Saskatoon, as shown in Fig. P6.6. One cannot observe a SAR-arc, at 400 km at Rapid City, without looking through a layer of 100 km green aurora. Hence an isolated red arc could not be easily seen at Saskatoon during the IGY. Perhaps it would be possible now.

Analysis of a Night at Which Red Aurora was Observed at Saskatoon:

In an attempt to elaborate on the above, a night was selected in which red aurora was present at Saskatoon, it was clear, and a SAR-arc was reported for Rapid City. The only night meeting these specifications was Nov. 15/16, 1960. This was the last of a storm that began on Nov. 12 and for which considerable red enhancement was reported in New Zealand. At Meanook, Canada (61.9°N geomag.) there was a little enhancement on Nov. 12, but none on Nov. 15/16. Saskatoon, slightly southward of this, did see red aurora, suggesting that the red forms may have a southern fringe on the aurora.

Patrol spectrograph data for this night was made available by Dr. A. Vallance Jones, and those spectra, along with selected all sky camera pictures, are shown in Figs. P6.7 and P6.8. In the first frame (17:40-17:55) of Fig. P6.7, the overhead arc is strongly red enhanced and visual observations indicate that the drapery in the east was also. Subsequently, the form exploded and dispersed, retreating to the north if anything. (Note added: The shadow height at this time was 175 km). It is therefore not possible to say where the arc went. At 20:00 the SAR-arc was detected at Fritz Peak -- this was the earliest time at which it could be detected because of twilight. At this time an arc was visible low on the southern horizon at Saskatoon -- but it was not particularly red enhanced. It would however, have obscured any SAR-arc present. Evidence of a faint red overhead form is seen from 22:40 to 23:30, remarkably stable in position, but again buried on normal aurora.

Conclusions:

One can conclude only that SAR-arcs bear a close association of position with aurora. It does not follow that the mechanisms need be the same, but it does mean that even had SAR-arcs been searched for, at Saskatoon during the IGY, they may well have been obscured by normal aurora. Perhaps IQSY would be a better time to look for them.

References:

1. Davis, T. N., J. Geophys. Res., 67, 75 (1962).
2. Akasofu, S. I., Annals of the IGY, XX, Part III, 331 (1964).

3. Black J. Private communication
4. Chamberlain, J. W., The Airglow and the Aurora, p. 206, Pergamon Press, London (1956).
5. Seaton, M. J., The Airglow and the Aurora, p. 225, Pergamon Press, London (1956).
6. Romick, G. J., Ph. D. Thesis, University of Alaska, (1964).
7. Manring, E. R., and H. B. Pettit, J. Geophys. Res., 64, 149 (1959).
8. Størmer, G., The Polar Aurora, Clarendon Press, Oxford (1955).

Captions

- Fig. P6.1 Representation of auroral distribution as seen from Saskatoon and Regina for the nights of Nov. 8/9, 9/10 and 10/11, 1957. Essentially, zenith angle is plotted versus universal time for the two stations. Local midnight at Saskatoon is approximately 6 hr. U.T. A vertical line with cross bar indicates an event and double hatching indicates cloud. The arc marked "red arc" indicates the time interval during which a SAR-arc was under observation at Rapid City.
- Fig. P6.2 Auroral distribution for the nights of Nov. 25/26, Nov. 31?/Dec. 1, and Dec. 10/11, 1957. See Fig. P6.1 caption for explanation of symbols.
- Fig. P6.3 Auroral distribution for the nights of March 11/12 and May 27/28, 1958. For the first night, auroral ASCAPLOT data is available for Rapid City as well. It is clear that aurora and SAR-arc were in close proximity. See Fig. P6.1 caption for explanation of symbols.
- Fig. P6.4 Auroral distribution for the nights of June 9/10, June 28/29 and Sept. 16/17, 1958. See Fig. P6.1 caption for explanation of symbols.
- Fig. P6.5 Auroral distribution for nights of Oct. 23/24 and Oct. 25/26, 1958. For the first night, aurora appeared overhead at Rapid City during the time at which a SAR-arc was being observed. See Fig. P6.1 caption for explanation of symbols.

Fig. P6.6 Showing the geometry for observation of a mid-latitude SAR-arc from Saskatoon. Differences in longitude of the stations are not considered.

Fig. P6.7 Patrol spectrograms and all-sky photographs for the first part of the night of Nov. 15/16, 1960. The orientation of the camera and spectrograph are shown in the Figure.

Fig. P6.8 Patrol spectrograms and all-sky photographs for the remainder of the night of Nov. 15/16, 1960.

Discussion of Topic 6*

Discussion leader: D. M. Hunten

Chamberlain asked how was it that Davis' picture and Akasofu's picture of synoptic aurora can be so different. Swift suggested that Davis is coming around to Akasofu's way of thinking about auroral morphology. Elvey pointed out that Davis' work was statistical whereas Akasofu's was an "event-wise" or "storm by storm" picture. Hunten said he did not get this impression from Davis' papers. Chamberlain asked if the two pictures weren't mutually exclusive. Elvey said that Davis would agree with Akasofu's description yet on the average the Davis picture emerges. Swift said there has been no case observed in which the "sun-earth-line-oriented" polar cap aurora actually joined up with the auroral zone forms. An extensive search for this was made. Cole asked if this might not be caused by the polar cap aurora getting fainter as it approached the auroral zone. Swift said they are definitely disconnected, in fact when there is an auroral breakup at the auroral zone the polar cap aurora tends to fade out.

Romick commenting on polar cap aurora said they have a station on the Arctic coast of Alaska at $77\frac{1}{2}$ gm. lat. and can easily observe to 80° . We have and are collecting information which may shed light on this phenomenon.

Swift said that at Ice Island T3 at times of $K_p = 0$ the quiet arc system sits at about 80° gm. lat. both day and night but as soon as there is any increase of magnetic activity the quiet arc rapidly shifts equatorwards. Cole asked, if and when the quiet arc at 80° gm. lat. broke up, did it do so like a miniature version of the break up seen at College (65° gm. lat.). Swift suggested that the observations were not clear on this point.

* Edited from the tape by K.D. Cole

Rees asked Shepherd whether the red arc on 1 November was sunlit or not. Rees said if it was sunlit then its spectral morphology was similar to that he observed 28-29 November. Hunten pointed out that the fact that it was sunlit has little to do with the red line in that aurora. The sunlight effect on the N_2^+ bands is marked and occurs at high altitude. There is, however, no appreciable resonance scattering of the red line. Rees agreed. Rees said the interesting thing was that during the 15th-16th November storm there was a red arc over Rapid City. Shepherd said that north of Saskatoon the red line enhancement was not observed, i.e., it was concentrated in the auroral form.

In relation to temperatures in high type A red auroras, Clark said: Even when far removed from any sunlight illumination, the nitrogen first negative bands in high type A red auroras in Alaska show occasional periods of enhanced vibration and rotation, loosely associated with unusually strong H Balmer emission. Atmospheric heating to temperatures around $3000^\circ K$ could account for much of the molecular enhancement; laboratory measurements of ion impact excitation confirm that protons are not capable of inducing very much vibration and rotation in charge transfer collisions.

On red arc spectroscopy, Clark said: We hope within the year to initiate routine spectroscopic observations along the magnetic meridian in the state of Washington, which is roughly equivalent in magnetic latitude to Rapid City.

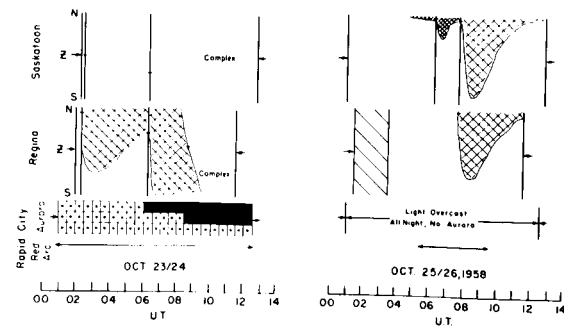
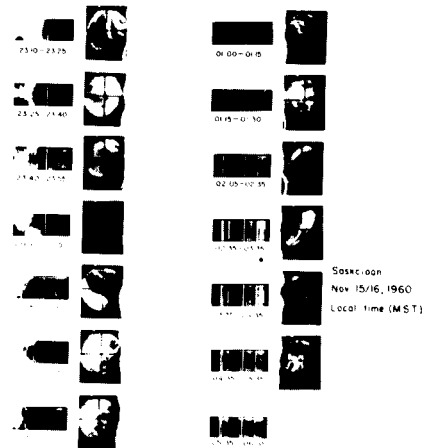
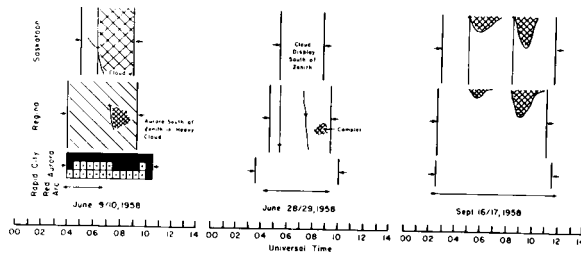
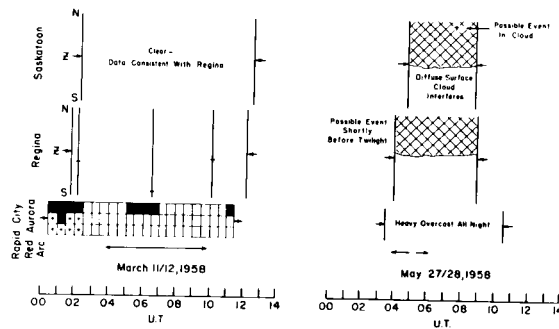
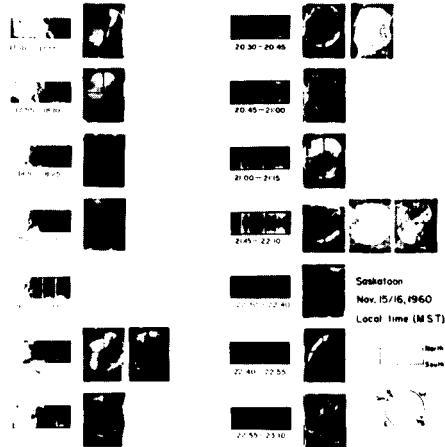
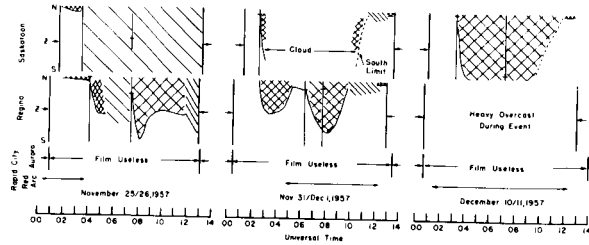
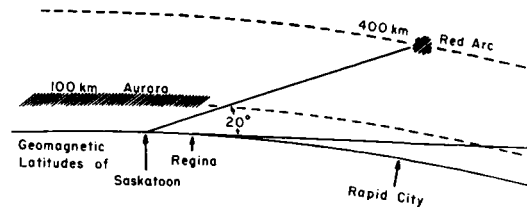
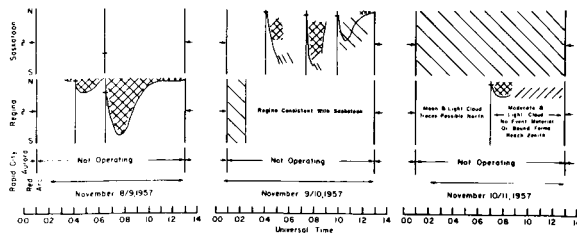
Reid asked concerning the methods of excitation of 6300. The SD current has electric fields associated with it and it is wondered whether these are sufficient to cause the 6300 on the model of Megill and Carleton. It would be good to seed the F region with a distinctive ionisable constituent in order to follow its movement and hence find out the electric fields. This observation done in conjunction with 6300 measurement from the ground should prove valuable.

Hunten said that Kavadas had already done some electric field measurements and Shepherd described them (see abstract and slides). Fields up to 1 v/m (D.C.) have been observed in aurora. After some discussion on the technique of measurement, Carleton said that large DC fields quoted are unbelievable because of the intense heating they would produce; for any such field existing at 140 km would also exist at higher altitudes. Hunten interjected that the measurements may not be truly DC but rather transient. Shepherd pointed out that Kavadas was now thinking in terms of electro-acoustic waves for their explanation. Swift said that Scarf, Fredericks and Krooks have measured large (1v/m) electric fields at VLF 1 kc/s.

Reid said that release of ions would be more direct than these methods for measuring DC electric fields. Dalgarno: Which ion would you suggest? Reid: I don't know, I don't know one ion from another. Laughter.

Swift pointed out that the motion of auroral forms may be useful in inferring electric fields. Hunten said that has a built in assumption. Swift agreed but that the method would be useful for test of consistency. Carleton said that radio star scintillation reveal ionospheric movement which may be just an EXB drift or could they be due to waves? Cole reminded people of the existence of gravity waves discussed by Hines.

King suggested the possibility of removal of a block of F region ionization by chemical means and following the movement of the irregularity thus created.



P 6.6 - P 6.8

P 6.1- P 6.5

TOPIC 7

A THEORY OF THE DST MAIN PHASE OF A MAGNETIC STORM INCLUDING THE SAR-ARC

K. D. Cole

PART I

This theory is based on the onset, duration, amplitude, and spatial distribution of geomagnetic fluctuations (noise) associated with a magnetic storm (see Fig. P7.1).

Geomagnetic fluctuations of period $\gtrsim 200$ seconds have associated with them electrostatic fields capable of causing the interchange of tubes of force in the magnetosphere. The random sequence of such electrostatic fields associated with geomagnetic noise pumps plasma from the outer to the inner magnetosphere, i.e., from higher to lower L values [Cole, 1964] (Fig. P7.3). The time constant for this redistribution of magnetospheric plasma is comparable to the interval between the onset of noise and the trough of the Dst main phase [Cole, 1964]. The main conclusions of Part I are [see also Cole, 1965b]:

(1) The process contributes largely to the depletion of plasma in the outer magnetosphere observed by whistler techniques (see Topic 15).

(2) In the process the magnetospheric plasma is energized sufficiently to cause a major contribution to the global decrease of the geomagnetic field.

(3) A belt of energized plasma (200-2000 ev in a storm of 100 γ) constituting a ring current is created near the lowermost L value of the noise region in the magnetosphere.

(4) Subsequent diffusion between the magnetosphere and the ionosphere tends to create a decrease of F region content at high middle-latitudes and an increase at lower latitudes (on L shells connected to the ring current).

PART II

(1) The SAR-arc is ascribed to thermal excitation by F region electrons. The cooling rate of electrons integrated throughout the volume of SAR-arcs is found comparable to the rate of decay of the energy of the magnetic storm as follows [see Cole, 1965a,b, for further details]:

Energetics of Dst Main Phase and SAR-arc

Dst Main Phase

Kinetic energy in trapped particles required to produce 100 γ storm = 3×10^{22} ergs = ΔE_n .

Suppose storm decays in 10^5 seconds

$$\frac{d}{dt} (\Delta E_n) = - 3 \times 10^{17} \text{ ergs sec}^{-1} = L (\text{Dst})$$

SAR-arc

In 100 γ storm intensity of SAR-arc is about 10 kR after sunset. Temperature of F region electrons in SAR-arc in 100 γ storm $\approx 3200^\circ\text{K}$. Cooling rate of electrons $Q(e) = \frac{3}{2} k n_e \{A n(O) + B n(N_2) + C n(O_2) + D n_1\}$. It is found

$$(1) \quad L(\text{Dst}) \approx \int_{\text{SAR-arcs}} Q(e) dV$$

(2) It is assumed that the F region electrons are kept hot by heat conduction from a decaying ring current. The condition is found in order that the ring current found in Part I, decaying by coulomb collisions with the thermalized component of magnetospheric plasma, provide enough energy for SAR-arcs.

(3) Protons in the ring current cool quicker than electrons. This would cause two different rates of decay of the main phase, a quick initial recovery (associated with protons) followed by a slower one related to electrons.

(4) A combination of the theory of Parts I and II provides a consistent account of most of the properties of SAR-arcs.

(5) It is pointed out that heat conduction from energized magnetospheric tubes of force may likewise account for a large proportion of the observed type A red aurora.

(6) Suggested tests of the theory are to be found in the references hereunder.

References

- K. D. Cole, "On the depletion of plasma in the outer magnetosphere during magnetic disturbance," J. Geophys. Res. 69, 3595-3601, 1964.
- K. D. Cole, "Stable auroral red arcs, sinks for energy of the Dst main phase", J. Geophys. Res. 70, 1689-1706, 1965a.
- K. D. Cole, "On the Dst main phase of a magnetic storm and certain associated phenomena", Physics of Geomagnetic Phenomena, Ed. by S. Matsushita and W. H. Campbell, Academic Press, 1965b.

Captions

- Fig. P7.1 Magnetograms from College, Fredericksburg and Honolulu for storm of September 25, 1958. Time intervals are 4 hours. The magnetograms are aligned roughly in U.T.
- Fig. P7.2 Illustrating diffusion in two dimensions.
- Fig. P7.3 Illustrating change in plasma distribution and energy brought about by random electrostatic fields in the magnetosphere.
- Fig. P7.4 Illustrating the energy flow envisaged in the theory.

Discussion of Topic 7 *

Discussion Leader: K. D. Cole

Rees showed slides which showed (i) the decay of SAR-arc luminosity with time (Fig. D7.1). The time constant was similar to that of normal F region decay, (ii) intensity versus Dst at the equator (Fig. D7.2), (iii) patrol spectrograms from Rapid City showing that in the SAR-arc there was no enhancement of $\lambda 5577$ (Figs. D7.3 and D7.4).

Walker asked what might account for the stability of the SAR-arc. Cole said that his theory would link the stability of the arc to the stability of a magnetospheric ring current which (decaying) was the source of energy for the arc. Swift added that the stability of the Dst main phase as seen on magnetic records from equatorial region is pertinent.

King made two comments (i) that SAR-arcs are readily detectable on ionospheric records and therefore such records could supplement photometric records at times of cloud and moonshine (ii) one should not use the King and Roach $n(h)$ profile to compare arc conditions with quiet conditions in the ionosphere in view of the fact that it may not be typical. He considered that there was probably a decrease in the content of the bottom of the F layer. More work needs to be done of $n(h)$ profiles in SAR-arcs.

Hanson asked if a diffusion time was derived by Cole for redistribution of magnetospheric plasma during storms. The latter replied 'yes' and that using a variance of the electric field noise and also a correlation time (derived from magnetograms) and assuming a noise region several earth radii thick in the magnetosphere a diffusion time was found to be similar to the time interval between the onset of noise and the trough of the main phase decrease.

* Edited from tape by K. D. Cole

Hanson asked why should there be a low L value limit on the position to which the magnetospheric plasma is driven by diffusion. Cole said that his theory would put this limit at the innermost L value at which significant geomagnetic noise existed during storms. During quiet times the noise is confined to a belt at high latitudes (and the lines of force connected thereto). During storms, the belt of noise develops equatorward but usually not all the way to the equator.

McElroy asked if there were times when you got geomagnetic noise not accompanied by a SAR-arc. Cole said he didn't know but that he had not seen a magnetic storm main phase decrease that was not accompanied by the noise.

Megill commented that mere observations of luminosity of the SAR-arcs will not be a good test for any theory because of the sensitivity of luminosity to temperature of electrons. To a steady heat flux into the ionosphere a decrease of electron density (as occurs during the night) should be accompanied by an increase of electron temperature. This is something that should be looked into. Another point is that satellite drag data show that there is a great deal of energy put into the atmosphere somewhere during storms and there is no evidence to say it is put in when the arc is. However, a calculation that Van Zandt and he did on the electric field hypothesis for the arc showed that you need the magnitude of energy dissipation found to get temperatures similar to those got from satellite drag data. However, the energy could be going into the atmosphere at some other place than the SAR-arc.

Commenting to Megill's last comment Cole said that, in his present talk, he was considering heating of the atmosphere due to the Dst component of disturbance (i.e. decay of a "ring" current). In the total disturbance $D = D_{st} + D_s$ the D_s part was associated with geomagnetic fluctuations and these, by Joule dissipation, would also be a source of heat for the high atmosphere. Preliminary calculations suggest that more heat is generated by D_s than D_{st} . The D_s heating, of course, peaks at higher latitude than D_{st} heating which goes in at the SAR-arc.

Carleton commented that electric fields involved in Cole's mechanism for plasma diffusion are comparable to those that Megill and he used to calculate the luminosity of the SAR-arc and the heating therein. Therefore, these fields would generate heating and luminosity as Megill and Carleton had shown. The difference was that of the morphology of the fields involved in the SAR-arc (assumed by M and C) and the morphology of the irregular fields used by Cole for diffusion. Such irregular fields may be called upon for explaining irregular dayglow in 6300.

Cole agreed that his irregular fields would do the heating that Megill and Carleton say such fields should do, but that a D.C. field was not involved in the SAR-arc after its formation (which would require an organized field of global dimensions and there are objections to this; see discussion led by M. H. Rees, Topic 3). The irregular fields are

part of the D_g process already discussed and occur poleward of the SAR-arc. The SAR-arc is an indirect outcome of the irregular fields whose action is to stuff hot plasma deep into the geomagnetic field. The cooling of this plasma gives the SAR-arc.

Carleton asked Van Zandt if the F region content was depleted during storm in some region and Van Zandt said that moon echoes showed this to be so during storms. Carleton asked if there was any evidence for an increase of content at lower latitudes during storms. Thomas said he knew of no storm which showed an increase of content. At low latitude ? (Cole) At any latitude (Thomas). King pointed out that at low latitudes during the day not at night after a storm when the activity has died away, there was interesting behavior. On one occasion when $K = 9$ was followed by $K = 2$ within a day and it remained there for a couple of K periods, the critical frequencies increased during the day. This behavior is associated with F1 structure as well, and he did not believe the ionization comes from above. He believed it comes from below.

Commenting on King's comment, Cole said that his model predicted an increase at the site of SAR-arc of F region content or at least a flux of ionization into the F region. When the hot plasma constituting a ring current had cooled off, i.e., in the late stages of a storm, it would diffuse into the F region and tend to increase its content.

John Roach asked if there were any ideas on the formation of a multiple SAR-arc system. Cole suggested that multiplicity was not inconsistent with his theory. One noise region would produce one SAR-arc. Noise at a subsequent time and on a region poleward of the equatorward edge of the first region could pump newly created magnetospheric ionization (created by auroral bombardment) to the inner magnetosphere to form a second arc and so on.

Swift said the morphology of stable auroral red arcs seems in many respects related to the apparent morphological features of the ring current responsible for the main phase of the magnetic storm. From these considerations, it seems worthwhile to study mechanisms of energy transfer between the hot magnetosphere plasma and the F region of the ionosphere.

He also said it is curious, however, that during the large magnetic storms that the SAR-arcs are observed during the recovery phase of the storm. Also, that it is during the less intense storms that the SAR-arcs observed during the most intense phase of the storm. This effect may be due to a lack of extensive enough observations. But this might also be a real phenomenon and should be studied in more detail.

Captions

Fig. D7.1 Zenith photon emission rate of a stable red arc as a function of time recorded by F. E. Roach and E. Marovich at Fritz Peak Colorado on September 29/30, 1957, Planet. Space Sci. 8, 197-201, 1961.

- Fig. D7.2 The relationship between the absolute intensity of mid-latitude subvisual red arcs and the earth's magnetic disturbance field Dst (H), Planet. Space Sci. 11, 105-107, 1963.
- Fig. D7.3 Patrol spectrograms of SAR-arc taken at Rapid City, S. D., during the nights of 5/6 September 1958 and 15/16 September 1958. On 5/6 September the SAR-arc occurred in the southern horizon while there was some auroral enhancement to the north of the station. Scattered moonlight accounts for the continuum and absorption spectrum in the blue region of the spectrogram.
- Fig. D7.4 On September 15/16 the SAR-arc occurred to the north of Rapid City at a zenith angle of about 30° to 40° , while weak aurora was present low on the northern horizon. This was a moonless night.
- Note particularly the difference in the $\lambda 5577$ and $\lambda 6300$ densities in the SAR-arc and the aurora. The photon flux in these SAR-arcs was only about 300 to 500 rayleighs.

SOME SUGGESTIONS FOR FUTURE INVESTIGATIONS ON THE SAR-ARC

K. D. Cole

The following is a compilation of some needed investigations on the SAR-arc together with the most obvious cogent reasons.

(1) We need to know n_e , T_e , T_i , T_g and atmospheric composition in and around the SAR-arc. This is in order to understand the energetics of the phenomenon (see reference 1). A knowledge of T_i and T_g will discriminate between the electric field theory and theories in which electrons are the initial heat source (see also McGill on page 88). n_e , T_e , T_i may be measured by backscatter techniques and it may be anticipated that SAR-arcs will eventually appear over the N-E of USA and even Arecibo. Rocket techniques may be used on all the measurements.

(2) It would be good to know the spatial distribution of magnetospheric plasma in the energy range 0-10 kev during storms. There are many indications that a significant ring current will be found in this energy range and that it is on geomagnetic field lines connected to SAR-arcs (see references 1,2). In this connection it may be noted that with the extension to greater altitudes of the detection capability of the Jicamarca backscatter device there is the possibility that the ring current during a great storm may be detectable (K. Bowles, personal discussion). In this case the occurrence of a SAR-arc on the same L shell as a ring current may be checked.

(3) We would like to know the contours of equal variance of surface geomagnetic field noise $\langle (\Delta B)^2 \rangle$ to check whether SAR-arcs form at the equatorwards edge of the noise region. (See reference 1)

(4) We need to know the isophote structure of the SAR-arc better. This is a complementary study to measurement of n_e , T_e , and composition *in situ*. Presumably the isophote structure may yield information on composition of the SAR-arc atmosphere (See reference 1, p. 1699).

(5) Absolute measurements of the velocity of radio scintillation sources should be compared with movement of luminosity patterns within the SAR-arc. Are these the same or different phenomena?

(6) We need to know whether the SAR-arc is formed *in situ* or whether it develops and moves equatorwards from higher latitude. This would have implications for the mode of introduction of energy into the geomagnetic field during storms.

(7) We need to know at what stage of the storm does the SAR-arc develop. This would help to clarify its association with a ring current.

(8) We need to know the relationship of the SAR-arc to the ionospheric storm. Does the position of the SAR-arc (bearing in mind possible multiplicity) demarkate different variations of the ionosphere as a function of latitude (see references 1, 2)? What is the $n_e(h)$ profile in a SAR-arc? How does the content in a SAR-arc differ from neighboring region? What E region exists under a SAR-arc? These questions have bearing on storm energetics.

(9) What is the relationship spacewise and timewise of SAR-arc to other ionospheric and magnetospheric phenomena, eg., the ionospheric troughs (see Topic 12) the magnetospheric knee (see Topic 15) field aligned sheets of ionization (see Topic 12) and normal aurora.

(10) There should be a search for distinctive daytime ionospheric phenomena at the latitude of the SAR-arc by all possible techniques, by photometry, radio scintillation (see also J. R. Roach, p. 87) and ionospheric sounding bottomside and topside.

Question by F. E. Roach, "How many mega-bucks will all that cost?"

References:

- (1) Cole, K. D., "Stable auroral red arcs, sinks for energy of the Dst main phase", J. Geophys. Res. 70, 1689-1706, 1965a.
- (2) Cole, K. D., "On the Dst main phase of a magnetic storm and certain associated phenomena" in Physics of Geomagnetic Phenomena. Ed. by S. Matsushita and W. H. Campbell, Academic Press 1965b.

COLLEGE

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FREDERIKSBURG

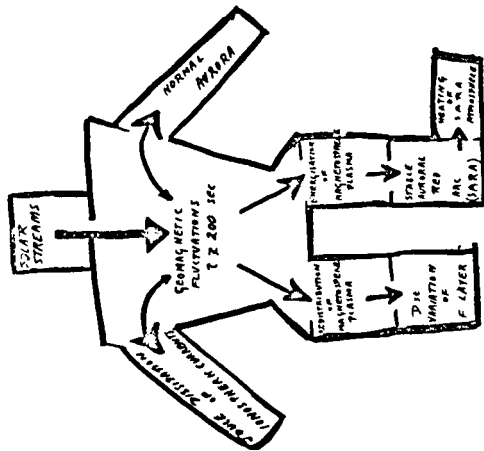
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SEPT 25 '58

P 7.1



GROSS ENERGETICS OF A STORM

P 7.4

IB HOMOGENEOUS

$$E + v \times B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

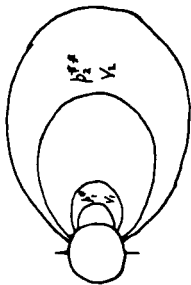
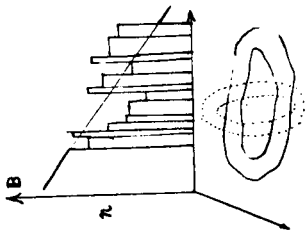
$$v = \frac{E \times B}{B^2}$$

$$D = \frac{\Delta \vec{r}}{\Delta t} = 2 \vec{v} \cdot \vec{r}$$

$$= 2 \vec{E} \cdot \vec{B} \cdot \vec{r}$$

$$t_2 = \frac{(\Delta \vec{r})^2 D^{-1}}{(\Delta \vec{r})^2 B^2}$$

$$= \frac{r^2}{E^2 \cdot r}$$



$B_0^2 \approx \frac{2}{3} \frac{\Delta E_n}{E_n}$

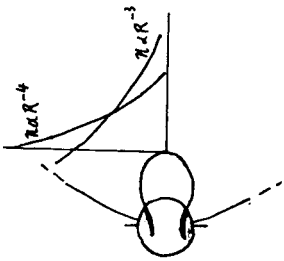
$100 \text{ V} \rightarrow 3 \times 10^{10} \text{ eV}$

10¹¹⁻¹² particles each at energy 200-3000 eV

$p v \frac{r}{B} = \text{constant}$

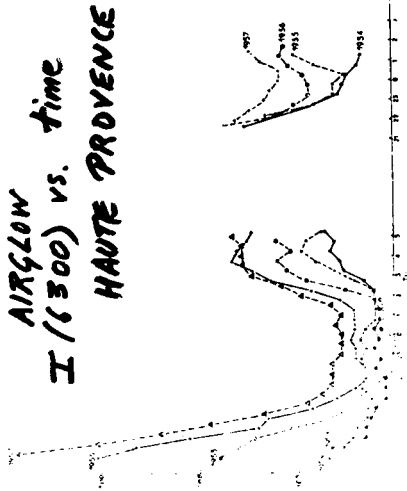
If $B^2 V_1 > B^2 V_2$

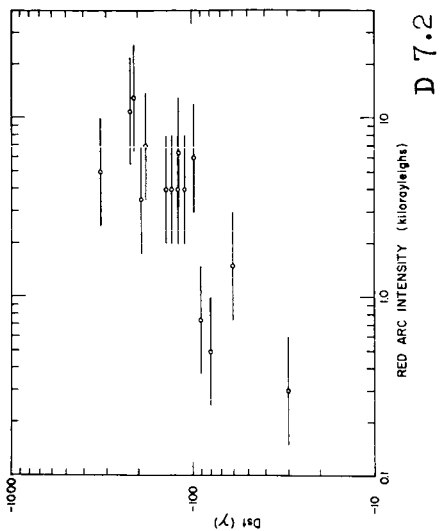
$\Delta E_n \Rightarrow B^2 V_2 \left(\frac{r_2}{r_1} \right)^{3/2}$



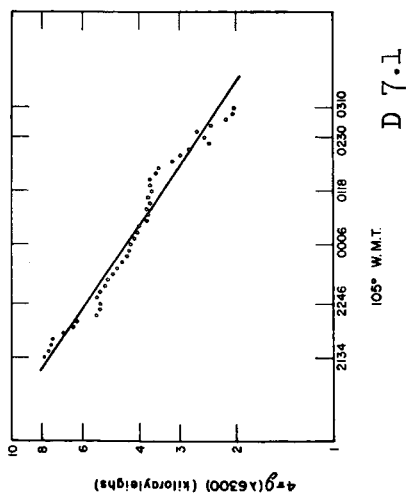
P 7.2

AIRGLOW
I (1500) vs. time
HAUTE PROVENCE

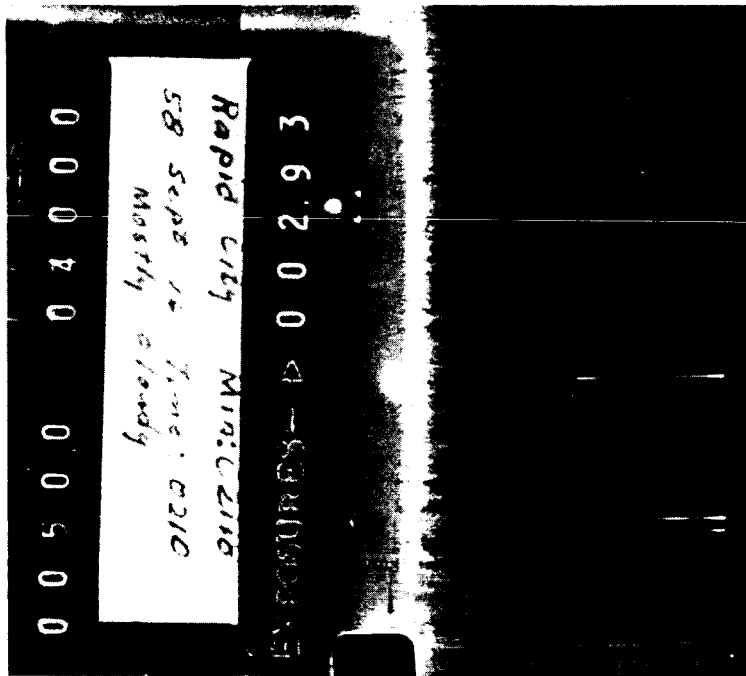




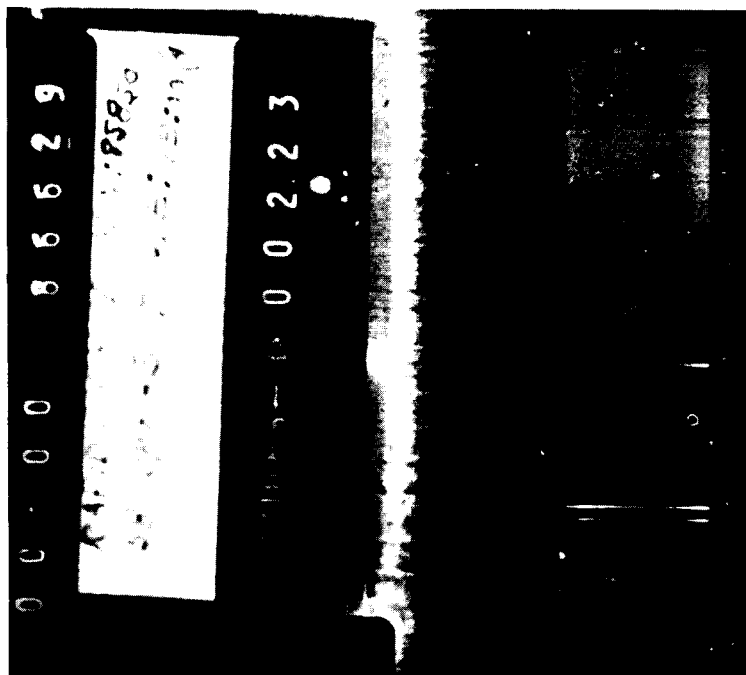
D 7.2



D 7.1



D 7.4



D 7.3

TOPIC 8

N₂⁺ IONS IN TWILIGHT AND POSSIBLE PRODUCTION MECHANISMS

A. L. Broadfoot and D. M. Hunten
Kitt Peak National Observatory
Tucson, Arizona

OUTLINE: New observations of the 3914 Å emission in twilight have been made at Kitt Peak throughout the past year. Seasonal and diurnal variations of intensity have been found; in the winter, when the intensity is highest, the evening/morning ratio is about 2; in the summer the intensity frequently drops below detection. The variation of intensity during twilight seems to be controlled mainly by the abundance of the N₂⁺ ion and not by shadowing. A height estimate, using zenith and horizon measurements, places the emission layer about 235 km and requires a screening height of about 100 km. This altitude is in agreement with the high rotational temperature observed in twilight, about 1500°K.

A continuous source of ionization during twilight is required. Solar ultraviolet and X-rays offer considerable difficulties. The likeliest alternative is a flux of electrons with energies in the tens to hundreds of eV. These electrons may well be produced photoelectrically; they may originate locally as well as at the magnetic conjugate point, which lies at a longitude about 1.3 hours farther west. Consideration of the time when the conjugate point is sunlit gives a natural explanation of the seasonal and diurnal variations. An estimate of the electron flux to be expected is consistent with the observations.

Discussion of Topic 8

Discussion Leader: A. Dalgarno

Three areas of interest were:

- (i) the reactions responsible for the twilight density of N₂⁺ (see following contribution by E. Ferguson)
- (ii) the other possible effect of photoelectrons during twilight, possibly coming from the conjugate point (see also following contribution by K. D. Cole)
- (iii) the possible excitation mechanisms with special relevance to the high rotational temperature. There was agreement that the measurements presented a serious difficulty.

On topic 8 Hunten said they needed a flux of energetic particles of about $3 \times 10^7 \text{ cm}^{-2} \text{ sec}^{-1}$ to create the necessary N₂⁺.

King pointed out that at Christchurch, New Zealand, they had found an effect after midnight on the F1 region that they thought could be attributed to back scattered photoelectrons.

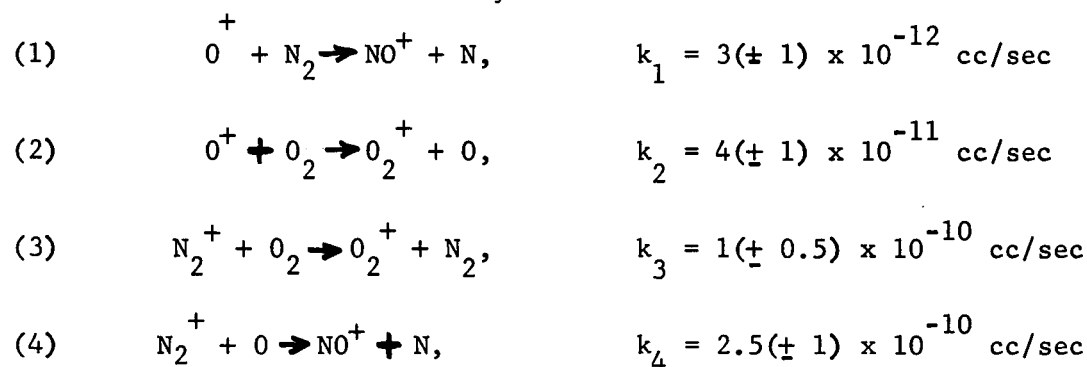
Chamberlain asked whether because of the geometry of the geomagnetic field the effect would not be evident in the American sector at dawn in winter. Cole and VanZandt pointed out that there would still be a residual effect but less than in the European sector (see also Ann. de Geophysique, No. 1, 1965).

Hunten commented on and gave an explanation for the existence of NaD lines in aurora. (See article in Journal of Atmospheric and Terrestrial Physics).

LABORATORY MEASUREMENTS OF REACTION RATES

E. E. Ferguson

We have recently measured rate constants for a number of ionospheric positive ion-neutral reactions at 300°K in the Atmospheric Collision Processes of CRPL. Of particular relevance to the discussions of this conference are the O^+ and N_2^+ loss rates. The following rate constants have been obtained in the laboratory:



The rate constants for reactions (1), (2), and (3) are supported by measurements in other laboratories. Reaction (4) has not been previously measured. These reaction rates are compatible with daytime equilibrium ionospheric positive ion concentrations in the E and F regions. We have made the qualitative observation in the laboratory that reaction (1) proceeds much more rapidly when the N_2 is vibrationally excited; this supports the suggestion arising out of the ionospheric studies of Thomas (see Topic 11).

THE PREDAWN ENHANCEMENT OF 6300 A AIRGLOW (SEE FIG. D8.1)

K. D. Cole

If one assumes that the enhancement is caused by thermal excitation by F region electrons one finds an electron temperature of about 2000° K for a 100 R enhancement. The integrated cooling rate of electrons matches closely the energy of photoelectrons backscattered from the magnetically conjugate atmosphere which is sunlit at the time (c.f. Fig. D8.2). The phenomenon is explainable both morphologically and energetically on the assumption that these photoelectrons heat the F region electrons by Coulomb collisions.

Reference

Cole, K. D., "The predawn enhancement of 6300 A airglow", Ann. de Geophysique, Issue No. 1, 1965.

Captions (Figures located on page 58).

Fig. D8.1 Intensity of 6300 A nightglow as a function of time at Haute Province, France, reported by D. Barbier in Ann. de Geophys. 15, 179-219, 1959.

Fig. D8.2 Eccentric dipole coordinates taken from Cole, Aust. J. Phys. 16, 423-429, 1963.

TOPIC 9

6300 A DAYGLOW AND THE POSSIBILITY OF DETECTING RED ARCS IN

THE DAYTIME

J. F. Noxon
Harvard University

There now exist observations of 6300 Å dayglow extending back to mid 1962. The great majority of these are ground based although a few rocket measurements have been of great value in sketching the distribution of intensity with height. The observations reveal a wide range of intensity (3-60 kr), but the higher intensities do not appear to be associated with magnetic activity, in contrast with red arcs. There is no information as yet on the degree of spatial inhomogeneity.

To identify stable red arcs in the daytime it will be necessary to study the spatial distribution of 6300 in the sky since the dayglow background is large. Balloon and rocket observations are hampered by expense and limited observing time despite the greater ease of discrimination. We therefore give principal attention to ground based detection schemes, mentioning techniques which measure either intensity or polarization of the skylight as a function of wavelength. We conclude that a 6300 brightness of 500 rayleighs or more might be detected in an area covering about half the sky; but the 6300 dayglow background is such that only an exceptionally bright red arc (> 10 kr) is likely to be detected by observations made from below the height at which the dayglow emission itself arises.

Fig. P9.10

POLARIZATION > 35 %

SKY INTENSITY $< 5000 \text{ KR} / \text{\AA}$

POLARIMETER	{	EBERT ($\sigma = 1 \text{ \AA}$)	I \geq 5 KR
		FABRY-PEROT ($\sigma = 0.1 \text{ \AA}$)	I \geq 0.5 KR (?)

$$\text{F.P. } \sigma = 0.005 \text{ \AA}$$

I > 20 KR (?)

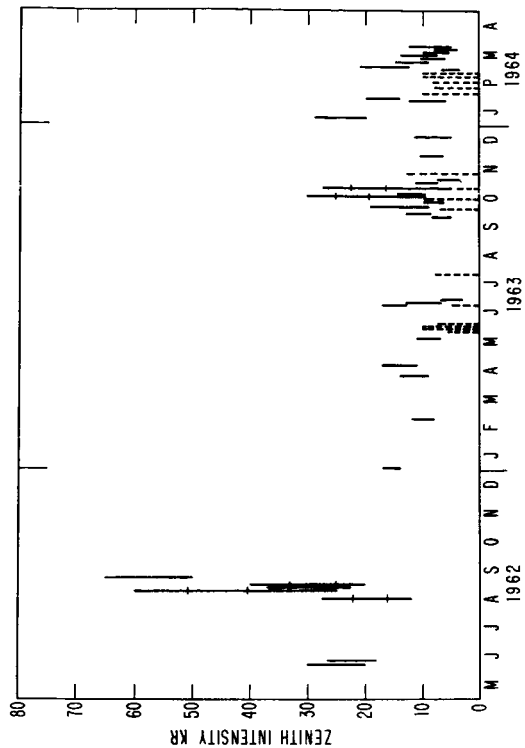
ORDER SPACING $\sim 1 \text{ \AA}$
PRE-FILTER $\sim 5 \text{ \AA}$

➤ 2-5 KR SUBTRACTING
SOLAR
SPECTRUM

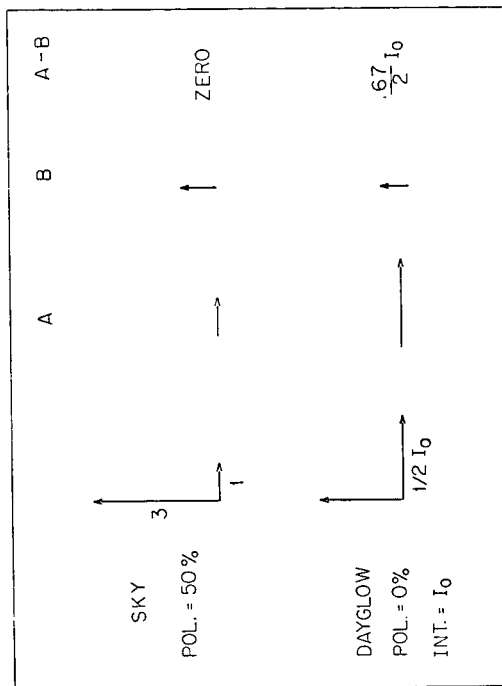
(OBSERVING FROM 100,000 FT. IS $\sim 100 \times$ BETTER)

CAPTIONS

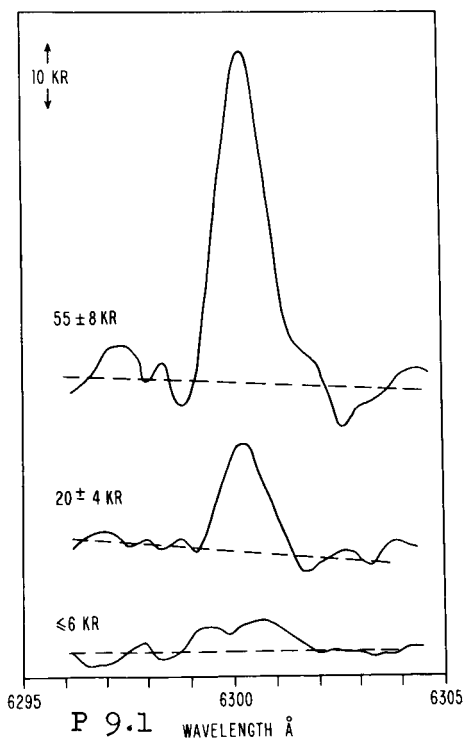
- Fig. P9.1 Some ground based spectra of 6300 A dayglow obtained in 1962 with a scanning polarimeter at 1 A resolution.
- Fig. P9.2 6300 A dayglow at midday 1962-1964. Dotted lines indicate that only upper limits could be measured.
- Fig. P9.3 Illustrates how 6300 A dayglow can occasionally vary greatly during a day; this day was magnetically quiet.
- Fig. P9.4 Basis of the scanning polarimeter technique. A polaroid in channel A is oriented to minimize the polarized sky signal seen at right angles to the sun. A pair of polaroids in channel B selects the maximum sky signal and then attenuates it to equal the channel A signal. This balance is upset when the scan reaches an unpolarized dayglow emission line.
- Fig. P9.5 Sketch of the arrangement of the scanning polarimeter.
- Fig. P9.6 Top: Two synthetic spectra to show what may be expected from the photographic Fabry-Perot technique used, for example, by Jarrett and Hoey. The irregularities result from the superposition of many Fraunhofer lines within the filter bandpass as seen in different orders. The irregularities set a lower limit of perhaps 20 kR on the brightness of a detectable 6300 dayglow.
Bottom: Solar spectrum near 6300 A to illustrate the Fraunhofer line problem.
- Fig. P9.7-9 Approximate portion of the sky in which the scanning polarimeter can be usefully employed is shown as a hatched area for three solar zenith angles. The non-useful area results either from the presence of low polarization or excessively high sky brightness.
- Fig. P9.10 An estimate for three techniques of the minimum detectable zenith 6300 A dayglow intensity for average sea level sky conditions with no clouds. The higher resolution Fabry-Perot polarimeter scheme has not yet been tried. The lower F.P. limit of 20 kR applies to the Jarrett-Hoey technique of photographing the sky through a F-P etalon with a pre-filter passing several others. The 2-5 kR limit applies to the case where a high resolution instrument passing only one order is combined with a rapid chopping between sky and sun so as to effectively cancel all common features such as Fraunhofer lines. In effect this is what has been done by Shepherd although without rapid chopping. (See page 42).



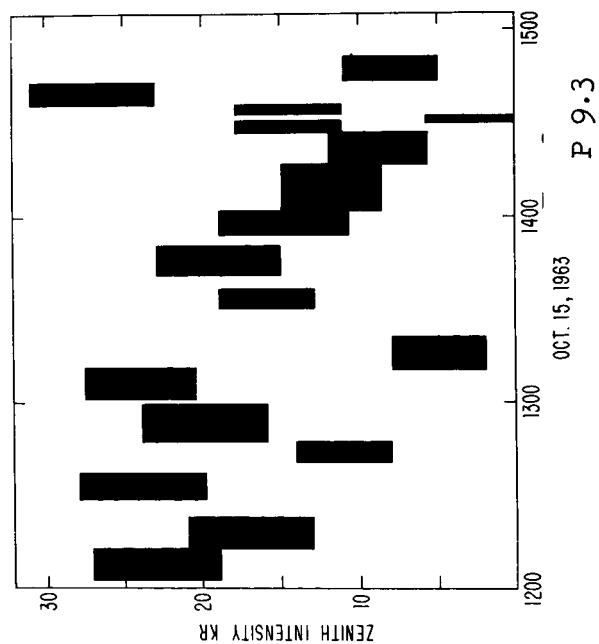
P 9.2



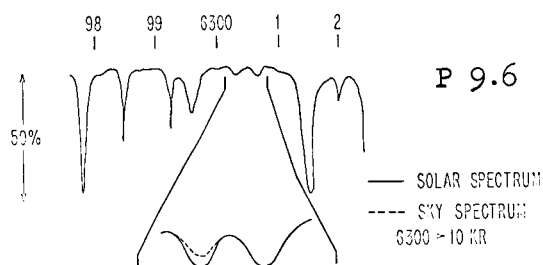
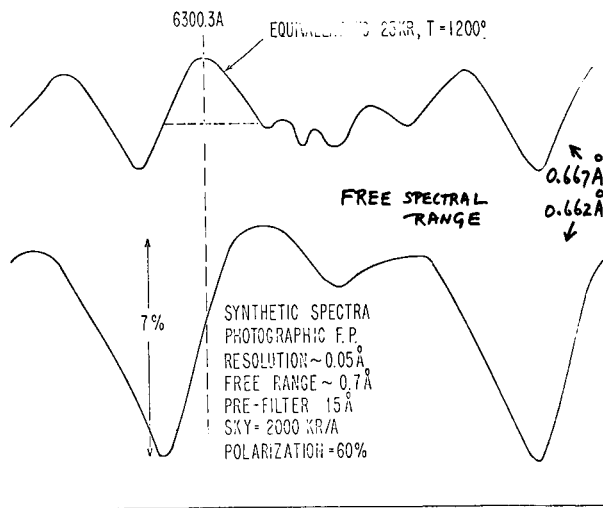
P 9.4



P 9.1

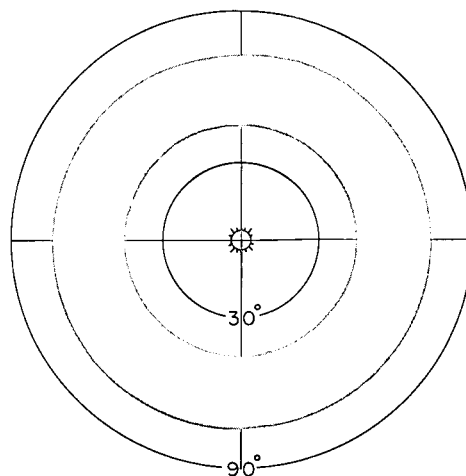


P 9.3



P 9.6

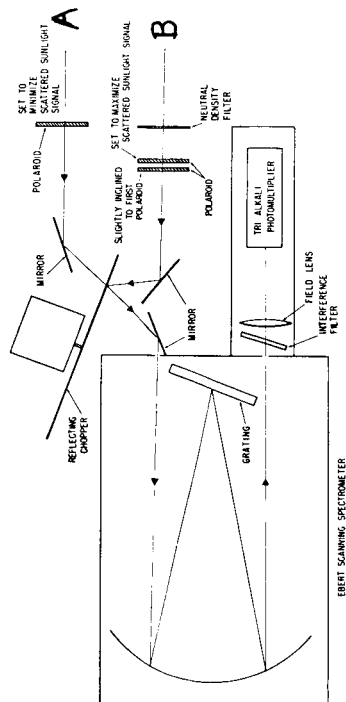
RAYLEIGH ATMOSPHERE MINIMUM INTENSITY = .015



POLARIZATION > 35%
INTENSITY < .06

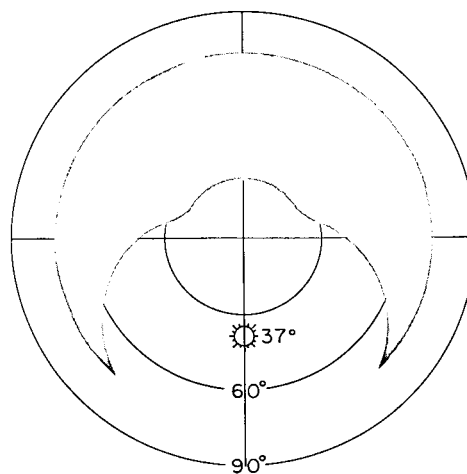
SUN AT ZENITH

P 9.7



P 9.5

RAYLEIGH ATMOSPHERE MINIMUM INTENSITY = .015



POLARIZATION > 35%
INTENSITY < .06

SUN AT 37°

P 9.8

SOME EXCITATION MECHANISMS FOR THE DAY AIRGLOW

M. B. McElroy
Kitt Peak National Observatory
Tucson, Arizona

OUTLINE: This paper discusses the physical processes responsible for the observed dayglow emissions at $\lambda 3914$ [N_2^+], $\lambda 5199$ [NI], $\lambda \lambda 5577$, the 6300 [OI]. We consider excitation by photoelectron impact, dissociative recombination, photodissociation, photochemical reactions, and resonance scattering as possible mechanisms. Estimates are given for the deactivation coefficients of $O(^1D)$ and $N(^2D)$. Our results are compared with recent photometric observations by Wallace (paper in preparation). The agreement obtained with the rocket intensities and with the differentiated rocket data is satisfactory.

EDDY DIFFUSION AND OXYGEN TRANSPORT IN THE LOWER THERMOSPHERE

F. D. Colegrove
Texas Instruments, Inc.
Dallas, Texas

W. B. Hanson and F. S. Johnson
Southwest Center for Advances Studies
Dallas, Texas

ABSTRACT

The O/O_2 concentration ratios above 100 km have been combined with knowledge of reaction and diffusion rates to construct a model of the neutral atmosphere between 80 and 120 km. The average eddy diffusion coefficient is determined within narrow limits by oxygen dissociation and recombination rates and by continuity requirements. The value of the eddy diffusion coefficient compatible with recent mass-spectrometer measurements is about $4 \times 10^6 \text{ cm}^2 \text{ sec}^{-1}$.

ROCKET MEASUREMENT OF THE PHOTOELECTRON - EXCITED

ULTRAVIOLET DAYGLOW

Charles A. Barth and Jeffrey B. Pearce
Jet Propulsion Laboratory, Pasadena, California

The ultraviolet dayglow was measured from NASA Aerobee 4.111 at Wallops Island, Virginia on January 13, 1965 at 1:48 PM EST. The 0.5 meter spectrometer scanned the spectral region 2100 - 4100 Å with a resolution of 10 Å. The rocket's attitude control system aimed the spectrometer at the horizon during the descent from the peak altitude of 179 km. The most important newly-discovered spectral features were the second positive bands of molecular nitrogen. Their excitation is the result of bombardment by fast photoelectrons in the upper atmosphere and not of fluorescent scattering. The intensity of the second positive bands provides a method of measuring the flux of photoelectrons. (see Fig. D9.1).

Discussion of Topics 9 and 10 *

Discussion Leader: J. C. G. Walker

Dalgarno noted that if one assumed the entire dayglow (green line) to be due to solar Lyman-alpha photoionization electrons it would be possible to set an upper limit on the contribution of Lyman-alpha at night. Asking what this limit would be, the answer was about 10 rayleighs.

To Hanson's abstract might be added that he found the product of the ratio of O/O_2 times the diffusion coefficient to be essentially constant, $4 \times 10^6 \text{ cm}^2 \text{ sec}^{-1}$ so that knowledge of one quantity fixes the other one.

Hunten pointed out that in order to do anything on dayglow interpretation the deactivation rates must be well known. To an already confused picture he brought out evidence that O_2 is not the deactivating species for $O(^1D)$ atoms. This concerns an experiment by Kvifte and Vegard (Geophys. Publ. 1947) in which they measured the quenching rate of $O(^1S)$ by O_2 . They found a rate coefficient of $3 \times 10^{-15} \text{ cm}^3 \text{ sec}^{-1}$ which compares well with the more recent results of Barth and Hildebrandt who obtained $4 \times 10^{-15} \text{ cm}^3 \text{ sec}^{-1}$ by an entirely different technique. Although Kvifte and Vegard did not analyse the red line data, the relative intensities, which they obtained in the experiment, where excitation was obtained by

* Edited from the tape by M. H. Rees.

electron impact, can only be explained if the quenching rates for the two excited states are about the same. Hunten examined other possibilities but concluded that N_2 remains as the most likely quenching species. Difficulties concerning spin reversal were pointed out, particularly since the required rate is about $10^{-10} \text{ cm}^3 \text{ sec}^{-1}$.

Barth reported results on a rocket dayglow experiment. The region 4000 Å to 2100 Å was monitored; the 3914 radiation, NO bands and N_2 2P.G. bands were detected. The N_2 2P. G. bands must be excited by photoelectrons with energy greater than 11 eV since a spin reversal is required from the ground state of the molecule precluding photon excitation. An intensity of several hundred rayleighs was obtained. This proved consistent with calculated prediction based on the photoelectron mechanism if 10% of the photoelectrons produced by the 160 to 460 Å⁰ solar flux excite the upper state.

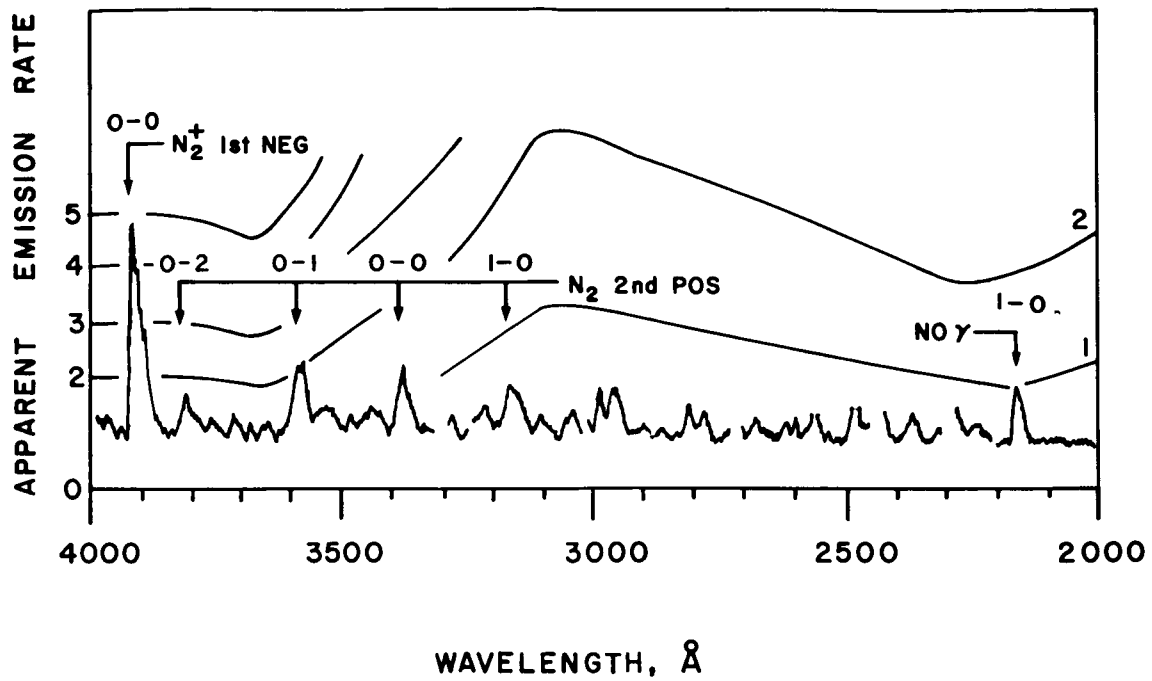
Walker concluded that the reason the red line is more complicated to explain than other dayglow features is that more observations are available on it than on any others.

Cogger said an attempt was made at Saskatoon to observe OI 6300 Å in the dayglow by photographic means. The experimental arrangement was similar to that employed by Jarret, Hoey and Paffrath, consisting of a Fabry-Perot interferometer of spacing 0.33 cm, a 61 cm focal length objective lens, and a 3.5 Å interference filter. The accompanying photograph shows the result (see Fig. D9.7). No emission was evident, but an interference pattern was produced by the presence of Fraunhofer structure. The experiment served to point out the difficulty one encounters in attempting to observe and measure dayglow emissions by this technique.

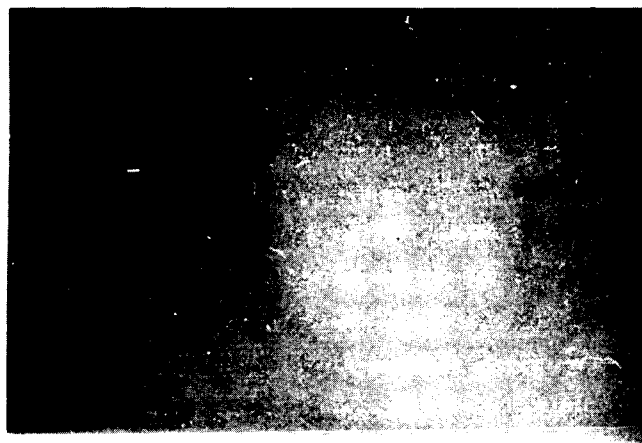
Captions

Fig. D9.1 Ultraviolet dayglow rocket spectrometer measurement (BARTH and PEARCE).

Fig. D9.2 Interference pattern from the day sky near 6300 Å (L. COGGER).



D 9.1



D 9.2

70

MAGNETIC AND IONOSPHERIC STORMS

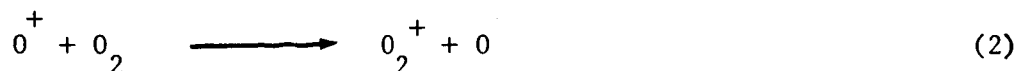
Lance Thomas⁺
NBS/CRPL
Boulder, Colorado

OUTLINE: A study has been made of the changes in the earth's magnetic field and of the F region disturbances occurring at middle latitudes during individual storms.

It has been shown that the onset and form of the ionospheric disturbances at a particular station are determined by the local time of the change in Dst (H) from the initial phase to the main phase and not that of the SC (Thomas and Venables, 1965a, in press).

On the assumption that the SD magnetic variations can be attributed to ionospheric currents, estimates have been made of the corresponding electric fields. The movements of the F layer derived from these fields have been compared with those deduced from observations of the layer. Agreement has been found on some occasions, but there are serious discrepancies. In fact, the major changes in height, which occur near the onset of the main phase of the magnetic storm, are observed over a wide range of latitudes and longitudes and cannot be reconciled with local electric fields (Thomas and Venables, 1965b, in press).

Calculations have been made to study the effects of increases in neutral gas, ion, and electron temperatures, which might occur during a magnetic disturbance, on the daytime distribution of ionization in the F region. Changes in layer height and shape can be expected but in order to account for the commonly observed depressions of NmF2 it seems necessary to invoke increases in the rates of the ion-atom reactions involved in the electron loss process:



Such increases could arise from increases in the molecular concentrations (Seaton 1956) or in the rate coefficients of (1) and (2). Bates (1962) has suggested that these rate coefficients will be dominated by electrostatic forces and will be independent of the gas temperature. The coefficients could, however, be influenced by internal excitation of O^+ ions or O_2 , N_2 molecules. It is suggested that vibrational excitation of N_2 by collisions with hot electrons produced during the magnetic disturbances could be particularly important. Such excitation may also occur by electron collision or fluorescence scattering during magnetically quiet days, but the increased electron temperature expected during disturbances

⁺ On leave from S.R.C. Radio and Space Research Station, Slough, Bucks, England.

could enhance the effect and cause the population of higher vibrational states. Laboratory measurements to examine this suggestion have been carried out recently at NBS/CRPL and have confirmed that the rate coefficient of (1) is increased when the N_2 is vibrationally excited (Ferguson, private communication) .

References

Seaton, M. J., J. Atmos. Terr. Phys., 8, 122, 1956.

Bates, D. R., "The Ionosphere", (London: The Institute of Physics and the Physical Society), Summary by H. Friedman, p. 94, 1962.

Discussion of Topic 11

Discussion Leader: S. Matsushita

Discussing Thomas' paper Matsushita commented as follows: The speaker found that "the onset and form of the ionospheric disturbances at a particular station as determined by the local time of the change is Dst (H) from the initial phase to the main phase and not that of the sudden commencement" (quoted from the abstract). If the ionospheric disturbance is defined as a large electron-density decrease in the F region, the speaker is certainly correct when dealing with the region higher than about 40° geomagnetic latitude. Thomas' discussion concerned the time immediately following the onset of the disturbance. It may be as well to point out that a density increase often occurs during the main phase of geomagnetic storms in middle latitudes in winter and in low latitudes all year (Matsushita, 1959).

The second point was that in view of the vertical electromagnetic drift theory, the local electric field attributed to geomagnetic disturbance variations should cause a height variation of the F layer, but no particular relationship was found. It may be necessary to take into consideration the horizontal electromagnetic drift effect.

References

Matsushita, S., A study of the morphology of ionospheric storms, J. Geophys. Res., 64, 305-321, 1959.

Commenting on SAR-arc events Matsushita said:

(1) Ionograms obtained at Ft. Monmouth during the SAR-arc events in 1958 show a clear occurrence of spread F and a density decrease in the F region which was slightly smaller than the normal amount caused by storms.

(2) The SAR-arc was observed not only during the main phase of geomagnetic storms but also during the last phase or recovery period. (Note added by Cole in editing: The theory proposed in topic 7 would associate the SAR-arc of the recovery phase with the decay in the "remnant" ring current then. In principle the physical mechanism is no different from that in the "main phase" except that the heat input may come more from energetic electrons than protons in the last phase of the storm (see Cole, K. D., JGR, 90, 1689-1706, section 3f, 1965). Also Matsushita said that small geomagnetic pulsations were sometimes observed during the SAR-arc events on non-disturbed days.

Matsushita mentioned other ionospheric disturbances which may occur. He said various types (see table on next page) of ionospheric disturbances are often associated with solar flare, PCA, sudden commencement and impulse, and the initial phase of geomagnetic storms (Matsushita, 1964; Obayashi, 1964). To discuss the onset of ionospheric disturbances a strict definition of the disturbance type is essential.

References:

- Matsushita, S., Geomagnetic storms and related phenomena, Res. Geophys.,
Ed. by H. Odishaw, MIT Press, 1, 455-483, 1964.
- Obayashi, T., Morphology of storms in the ionosphere, Res. Geophys.,
Ed. by H. Odishaw, MIT Press, 1, 335-366, 1964.

*IONOSPHERIC VARIATIONS ASSOCIATED WITH VARIOUS DISTURBANCE PHENOMENA

	D Region	E Region	F Region	Remarks
Solar Flare	N_e increase	N_e increase in the bottom region	Occasional density increase	Sunlit hemisphere
PCA	N_e increase			Polar region
SC and SI	N_e increase	Es		Occasionally in high latitudes
Initial Phase			Slight density increase	Middle and high latitudes
Bay	N_e increase	Es formation	Density increase	Auroral zone

Further discussion of Topic 11

VanZandt asked Thomas to clarify his statement about any possible change in behavior of F region storms as regards the position of SAR-arcs. Thomas said that he had seen cases where the storm behavior north and south of the SAR-arc was the same. (Comment added by Cole during editing of tape: SAR-arcs have been observed to be multiple.) Thomas said that he considered the SAR-arc to be a special situation within the more general ionospheric storm region.

King said that at Christchurch (N.Z.) they divide F region disturbances into four different classes. (1) They believe due to ionospheric drift seen in the afternoon especially in winter; (2) what appears to be current flow along lines of force especially at night time and high latitudes and sometimes in daytime at high latitudes, rarer in daytime at low latitudes; (3) a class probably due to high electron temperatures to which they believe SAR-arcs to belong; (4) changes in recombination most clearly seen in the daytime. In the daytime one can distinguish between this and the other classes by going to the F1 region where lifetime of electrons are so short that only recombination can have an influence. There appears to be more than one process for increasing the recombination: (1) occurrence of waves in the atmosphere spread from auroral activity; they mix the atmosphere; (2) auroral activity overhead causes the atmosphere to be well mixed.

Swift pointed out that, when the ring current forms, one also observes an increase in auroral substorms. These substorms start near midnight. Substorms often overlap. It appears that SAR-arcs are independent of normal auroral activity. SAR-arcs appear to be morphologically related to the ring current rather than to high latitude activity.

Shortage of time led to termination of the discussion.

POSSIBLE MAGNETOSPHERIC EFFECTS ON THE HIGH-LATITUDE IONOSPHERE

G. E. K. Lockwood
DRTE
Ottawa, Canada

SUMMARY: Three high latitude phenomena are observed which show some connection with the magnetosphere--the topside G-condition (Nelms and Warren, 1964), high latitude spread F (Petrie, 1964), and the "main trough" (Mul-drew, 1965) in foF2. The variation of the phenomena with time and magnetic activity is described.

References

Nelms, G. L. and Warren, E. S. - Space Research V, Proceedings of the fifth international space science symposium, Florence, May 1964.

Petrie, L. - presented at AGARD, Copenhagen, 1964.

Muldrew, D., J. Geophys. Res. 70, June 1st. issue, 1965.

Captions

Fig. Pl2.1 Ionogram and profile illustrating topside G-condition, spread at the satellite, and spread F.

Fig. Pl2.2 Ionogram showing the variation in spread with latitude.

Fig. Pl2.3 Variation of fxF2 with latitude.

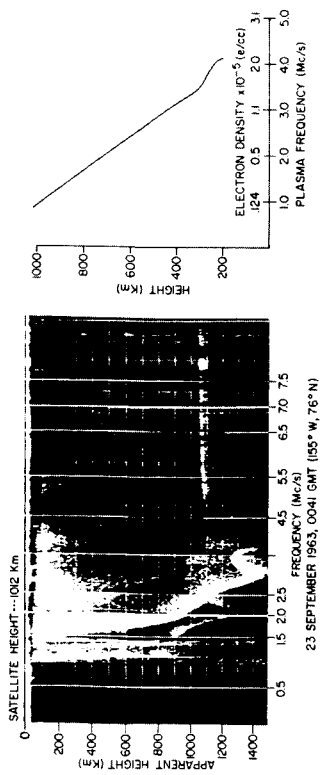
Fig. Pl2.4 Contour plot of fxF2.

Fig. Pl2.5 Diurnal variation of the latitude of the main trough.

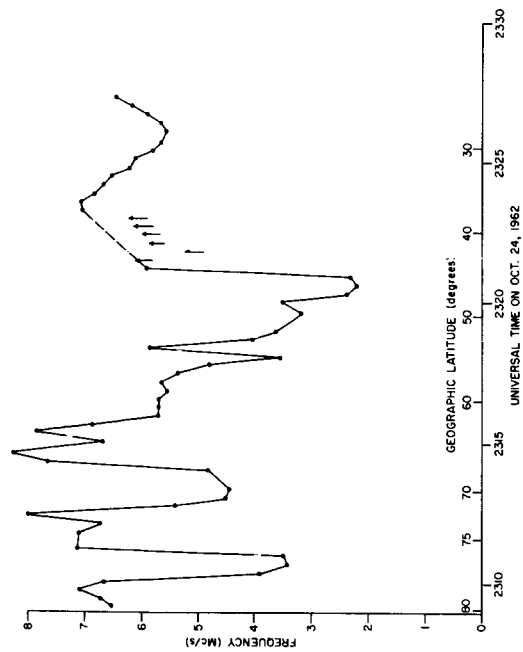
Fig. Pl2.6 Variation in latitude of the main trough with magnetic activity.

Fig. Pl2.7 Latitudinal range of spread F for February 8, 9, 10, 1963. Magnetic index, Ap, is also shown.

Fig. Pl2.8 Geomagnetic variation with local time of the location of maximum spread at the satellite.

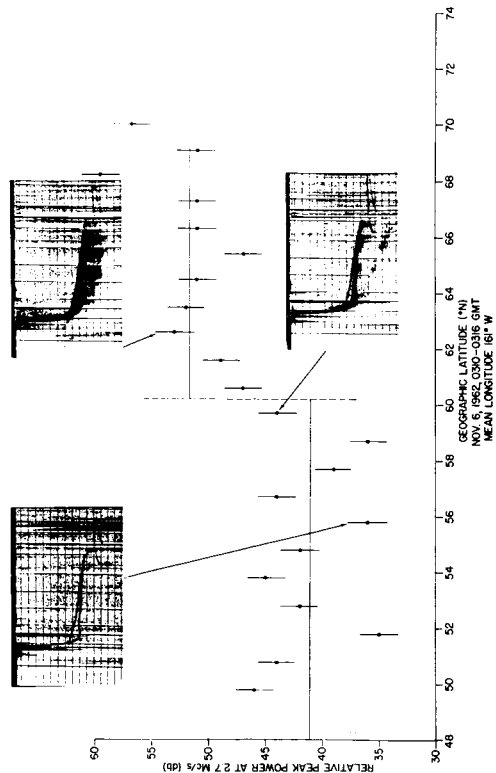


P 12.1

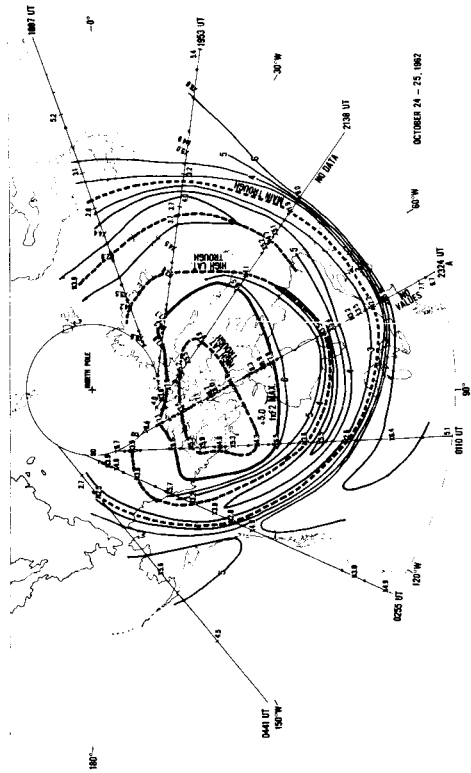


P 12.3

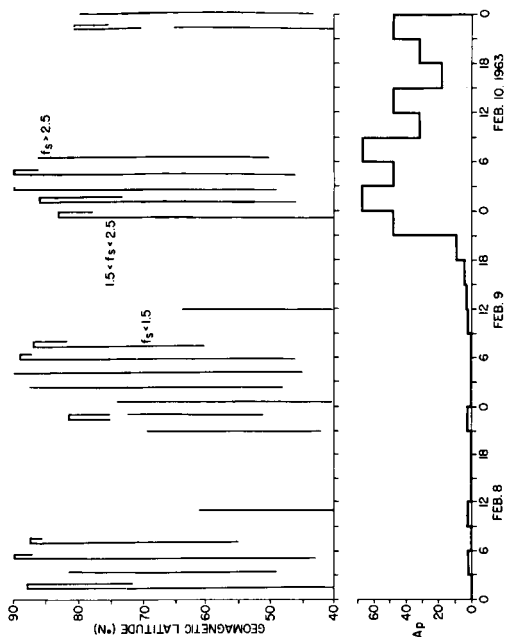
22



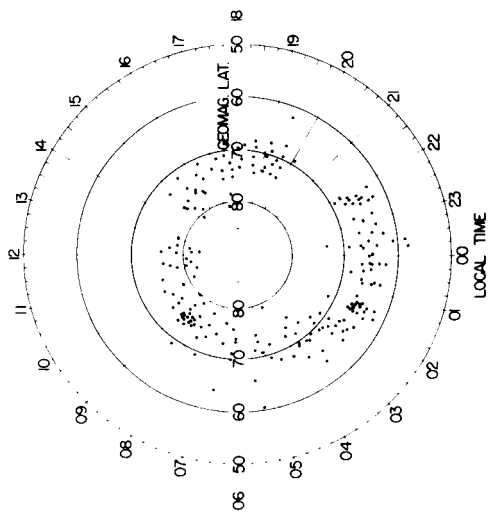
P 12.2



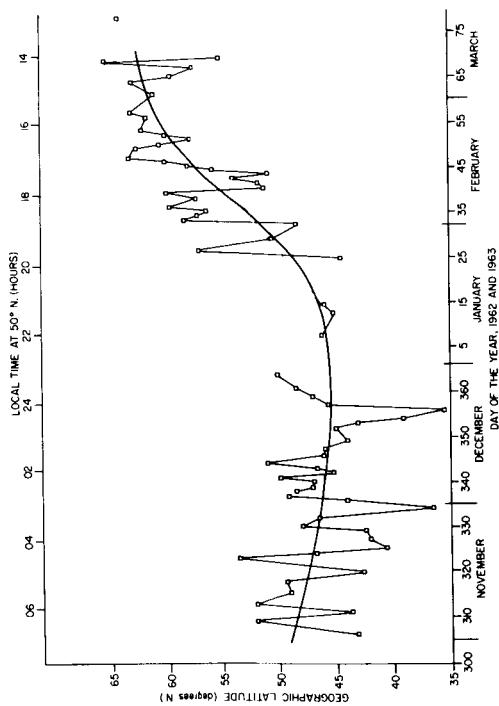
P 12.4



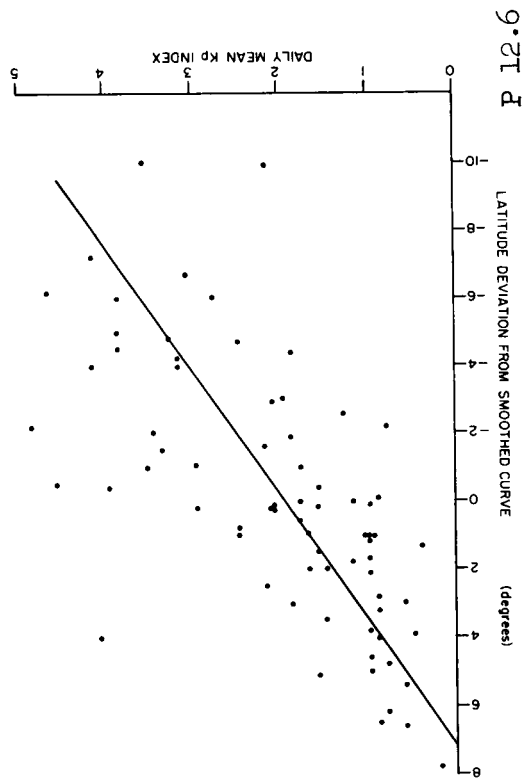
P 12.7



P 12.8



P 12.5



P 12.6

Main Trough

In answer to a question from Thomas, Lockwood confirmed that the distinction between the "main" and "first" high latitude" trough was real. After some discussion it was agreed that the variation in latitude of the main trough with local time did not correspond to the change in radial distance of the "knee" in the magnetosphere as found by Carpenter. Reid pointed out, however, that the change in position of the trough was similar to that found for proton aurorae as described previously by Romick. In reply to a query from Cole, Lockwood stated that an attempt had been made to relate the main trough with stable red arcs. Thomas noted that the change in latitude of the trough with Kp shown by Lockwood would suggest that at midnight the trough is located in the latitude region of red arcs for a Kp value of only 3 to 4.

HORIZONTAL GRADIENTS IN IONOSPHERIC ELECTRON CONTENT AT
MIDDLE LATITUDES

R. V. Bhonsle

Differential Doppler data recorded by the Applied Physics Laboratory of the Johns Hopkins University near Washington, D.C. on two harmonically related frequencies (54 and 324 Mc/s) transmitted from Transit 4A satellite during 1962 has been analyzed to study the variation of ionospheric electron content with latitude of the sub-ionospheric point. 259 satellite passages covering the period from February 1962 to September 1962 were analyzed using the method described by Garriott and de Mendonce (section D, 1963) and the results were plotted in terms of the total electron content against geographic latitude of the sub-ionospheric point. The trends of diurnal, seasonal, and solar cycle variation of the ionospheric electron content and the equivalent slab thickness of the mid-latitude ionosphere have been described elsewhere (Bhonsle et al., 1965).

First, it should be remembered that mid-latitude red arcs ('M' arcs) or SAR-arcs were not reported during the year 1962. This is not surprising in view of the fact that SAR-arcs are generally associated with severe geomagnetic disturbances. Secondly, none of the geomagnetic storms which occurred in 1962 were severe, although some moderately severe geomagnetic disturbances were reported. However, it should be of some interest to know how the north-south horizontal gradients in ionospheric electron content suffer modification during moderately severe geomagnetic storms.

* Edited from the tape by L. Thomas

Figures D12.1 (a), D12.1 (b) and D12.1 (c) represent a sequence of three latitudinal plots of electron content around the same local time on three different days. Figure D12.1 (a) represents a horizontal gradient in electron content on August 3, 1962 (a quiet day) at 2235 UT, which shows a monotonic decrease in electron content toward northern latitudes. Figure D12.1 (b) illustrates an effect of geomagnetic storm on August 7, 1962 at 2145 UT (ΣKp (9h) = 12) on the horizontal gradient of electron content. The storm began at 1400 UT on this day. Note the decrease in electron content from 32°N to 36°N geographic latitudes and the increase in electron content at latitudes greater than 40°N. Clearly, this indicates a major modification of horizontal gradient normally seen, as in Figure D12.1 (a). Figure D12.1 (c) shows a latitudinal plot of electron content a few hours before the end of the storm on August 9, 1962 at 2030 UT, when the normal horizontal gradient was re-established. The storm ended on August 10, 1962 at about 1400 UT.

Figures D12.2 (a), D12.2 (b) and D12.2 (c) show a similar sequence of latitudinal plots of electron content. For this instance, storm began on August 21, 1962 at 1700 UT and ended on August 25, 1962 at 1000 UT. Note the reversal of NS horizontal gradient beyond 44°N geog. latitudes on August 22, 1962, which was the second day after the commencement of mag. storm. Normal gradients were restored after the end of the storm, as can be seen from Fig D12.2(c).

The decrease in electron content at middle latitudes can be understood in terms of increased loss rate of ionization due to additional atmospheric heating during magnetic storms. But, in order to explain the increase of electron content toward northern latitudes, an additional source of ionization and heating, perhaps, corpuscular in nature becomes necessary.

Finally, Figures D12.3 (a) and D12.3 (b) show two typical examples of large scale irregularities in the ionosphere with departures on the order of 10% from the background ionization and horizontal scale sizes on the order of few hundred kilometers. Such large scale irregularities do not seem to be directly connected to magnetic activity, since these can be observed even during magnetically quiet periods.

References

- Garriott, O. K. and de Mendonca, F. - "A Comparison of Methods for Obtaining Electron Content from Satellite Observations," J. Geophys. Res., 68, pp. 4917-4927, 1963.
- Bhonsle, R. V., Aldo V. da Rosa and O. K. Garriott - "Measurements of the Total Electron Content and the Equivalent Slab Thickness of the Mid-latitude Ionosphere," to be published in Radio Science J. Res., NBS, Vol. 69D, July 1965.

Captions

- Fig. D12.1 (p. 84) Effect of magnetic storm of August 7, 1962 on the north south gradient of electron content in the ionosphere. Note, for latitudes greater than 36°N (geographic), increase in electron content toward northern latitudes on August 7, 1962 (a disturbed day) and, for latitudes between 30° and 46°N (geographic), decrease in electron content toward northern latitudes on August 3, and 9, 1962 (quiet days).
- Fig. D12.2 (p. 84) Effect of magnetic storm of August 22, 1962. Note, for latitudes greater than 44°N (geographic), increase in electron content toward northern latitudes on August 22, 1962, (a disturbed day) and decrease in electron content towards north on quiet days.
- Fig. D12.3 (p. 84) Large scale irregularities in the electron content of the ionosphere. The departures from background ionization are on the order of ± 5 to 10% and horizontal scale sizes on the order of a few hundred kilometers.

FIELD-ALIGNED SHEETS OF IONIZATION IN THE ARCTIC IONOSPHERE OBSERVED

BY EXPLORER XX

R. W. Knecht

Abstract

On August 25, 1964, the second satellite in the international topside sounder program was launched into a near-circular polar orbit from the Western Test Range in California. The first satellite launched in the topside sounder program was the Alouette satellite launched in late September 1962. The principal experiment on board that satellite is a sweep frequency topside sounder that covers the range from about $\frac{1}{2}$ megacycle to 12 megacycles every 18 seconds. Alouette has provided a vast amount of new information concerning the structure and composition of the region of the ionosphere from the F layer maximum at about 300 kilometers up to the altitude of the satellite at 1000 kilometers.

The second satellite in the program, the fixed frequency topside sounder (Explorer XX), has been designed to complement the sweep frequency soundings being obtained by Alouette. Explorer XX, rather than sweeping continuously over a wide range of frequencies, sounds sequentially on each of its six fixed frequencies between 1.5 and 7.22 Mc/s. This means that the satellite obtains sounding information on a given frequency with

a horizontal resolution of about 800 meters along the satellite path rather than the 120 kilometers which Alouette moves between successive soundings. Consequently, it can be seen that, while Alouette provides excellent information on the vertical profile on ionization on the topside of the F region, it is not well suited for the observation of horizontal fine structure or irregularities. On the other hand, Explorer XX was designed specifically to obtain information on the size, spacing, and nature of the ionization irregularities present in the high ionosphere. Some preliminary results concerning one specific type of ionization irregularity that has been frequently observed at high latitudes are described below.

On almost all passes of the satellite over the northern auroral zone and polar cap during the first weeks of the satellites' life, extensive field-aligned sheets of ionization irregularities were encountered by the satellite. As the satellite approached the sheets of irregularities, scattered echoes that decreased in range were observed. The range of these scattered returns decreases to zero at the time that the satellite apparently penetrates the sheet of irregularities. Subsequently, the satellite emerges from the sheet and again scattered returns with increasing ranges are observed. By noting the degree of scattering on the various sounding frequencies, the time during which the satellite is immersed in the sheet, the location of the sheet penetrations as a function of latitude and longitude, a number of the properties of these field-aligned sheets can be deduced.

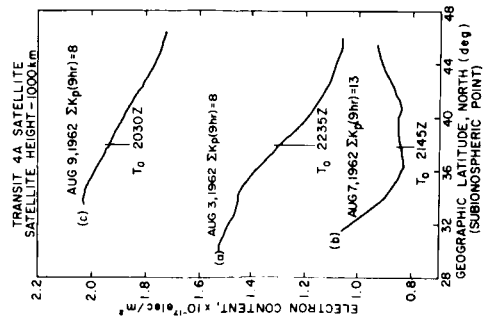
The results summarized here are based primarily on an analysis of the first several weeks of data obtained at the College Alaska telemetry station. An average of about two sheet penetrations occurred during each of the passes recorded at College. (The passes are about 2000 Km long on the average.) Based on the time that the satellite was immersed in the sheet, the thickness of the sheets along the satellite trajectory varied between a few tens of kilometers to 100 kilometers or more. Often a complex of sheets was present having an overall thickness of 150 kilometers or more with individual sheet thicknesses of the order of 10 kilometers indicated. A study of the frequency dependence of the scattering from the sheets suggests that individual scale sizes of the order of 15 to 20 meters are present in large numbers but that scale sizes as small as 10 meters or less are not frequent. Analysis of successive passes of the satellite shows that on occasion the sheets appear to remain relatively stable for periods of 4 to 5 hours. Though the analysis was not conclusive on this point, there did not seem to be a marked preference for a particular time of night with regard to the formation of these irregularities. A mass plot of more than 100 sheet penetrations during the initial three week period shows them to be located primarily north of the auroral zone maximum. The strength or intensity of the irregularities relative to the background electron density is difficult to estimate but the observations suggest that enhancements of between several percent and 30 to 40% are present in the irregularities.

An intercomparison program between all-sky camera observations of visual aurora and sheet penetrations at 1000 kilometers as observed by Explorer XX has begun. So far comparisons have been made on only two nights in early February 1965. On one night, as the satellite passed from south to north over western Alaska, no aurora was observed on the all-sky camera records and no sheet penetrations were observed by the satellite. On the second night, during a north to south pass over eastern Alaska, the satellite passed directly over an auroral form observed to the north of College by the College all-sky camera. Within the accuracy of the data, it appears that a strong sheet penetration which was observed in the satellite data occurred at just the time that would be expected if the visual auroral form was projected upwards along the inclined field lines to the 1000 km level. It seems reasonable to conclude, therefore, that some of the ionization irregularities observed at high latitudes by Explorer XX in the form of sheets are caused by the same incoming particle streams responsible for producing the aurora. This would appear to be the first definite evidence that certain types of field-aligned irregularities in the high F layer are associated with incoming particles. In order to make this association more conclusive, additional comparisons between sheet penetrations and all-sky camera observations are in the process of being examined in a cooperative program with the Geophysical Institute of the University of Alaska.

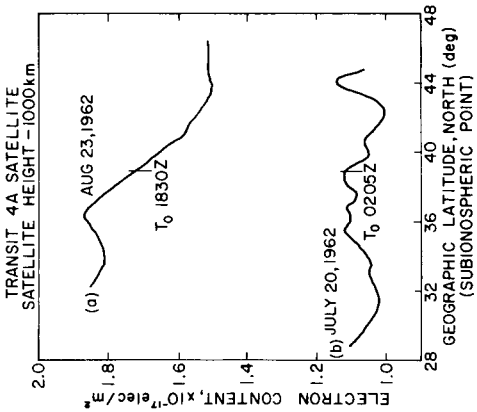
Spread F

King suggested that transmissions from suitably placed ground stations could help in estimating the size of irregularities giving rise to spread F.

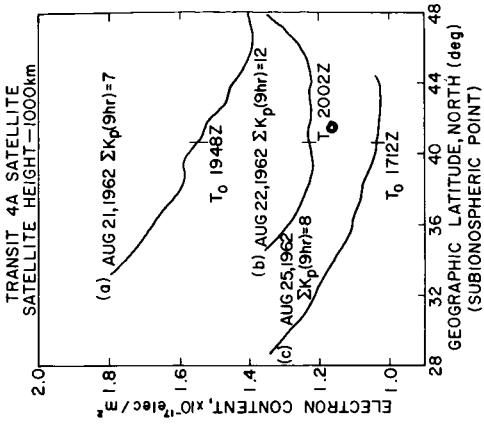
Thomas drew attention to two mechanisms proposed recently for the generation of field aligned irregularities which would imply an association between the spread F condition and atmospheric emissions. Herman has suggested that columns of ionization would be produced by high energy protons entering the atmosphere along spiral paths about the earth's field; from the proton fluxes required, considerable $H\alpha$ and 3914 \AA emissions might be expected. Bowhill has suggested that field-aligned irregularities could arise from differences in electron temperature between neighboring tubes of force; if the electron temperature is sufficiently high in certain regions excitation of the $O(^1D)$ state and the subsequent emission of 6300 \AA might be expected. It appeared that there was no evidence of an association between spread F and atmospheric emissions but Swift mentioned that field aligned irregularities were being studied by Bates at College and an attempt to correlate these irregularities with usual auroral was planned.



D 12.1



D 12.3



D 12.2

CONNECTION BETWEEN RED ARCS AND SCINTILLATION

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OUTLINE: There are several published reports on the close relation between red arcs and satellite scintillation (J. Roach, 1963; Yeh and Swenson, 1964). Low frequency radio signals encounter especially marked irregularities in the F region at times when arcs are present, and in exactly those parts of the sky occupied by the visible aurora.

Radio-star scintillations provide another datum towards clarification of the structures involved. The signals from the stars are broadband and permit discussion of scintillations as a function of frequency. Unfortunately, owing to several irrelevant circumstances, the most powerful technique for observing the scintillations, by the swept-frequency interferometer, has not been directly applicable to red arcs as yet.

Nevertheless, several conclusions can be drawn fairly directly from existing fragmentary observations. They follow from the premise that the relatively slow scintillations observed outside of red arcs are morphologically identical to the exceedingly fast scintillations observed along ray paths that penetrate the arc. This premise is demonstrably good for the fastest scintillations observed by the radio spectrograph. These scintillations are as fast as those observed through the red arcs. The problem is simply that no optical observations of the red arcs have been possible simultaneously with radio spectrographic observations here in Boulder.

Inasmuch as only the rate of the scintillation varies at these times when compared with quiet conditions, and not its bandwidth, angular variations, or intensity, we believe that it is appropriate to equate the structures observed at times of red arcs to the structures observed under normal conditions.

The necessary and sufficient conditions to explain the scintillations is that there then exist waves in the red arc whose phase velocities are of the order of magnitude of one kilometer per second.

References

- Roach, J. R., J. Res. Nat. Bureau of Standards, 67, 263, 1963.
Yeh, K. C. and J. W. Swenson, Jr., Radio Sci. 68D, 881-894, 1964.

STABLE RED ARCS AND THE IONOSPHERE

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OUTLINE: Describes the ionograms taken at times of red arc activity, pointing out the decrease in F region densities and the increase in E region densities. Compares with changes in the ionosphere during normal auroral activity.

INTERPRETATION OF ECHOES, 04 SEPT. 1959. IONOGRAMS AND RED ARC.

Circle Plots at Lauder

Time U.T.	Radio Distance (degrees)	Optical Dist.	Identification
0750	4.1	1.8	2
0759	2.1		
0820	4.1	1.7	2
0834	1.9		
0842	1.7		
0850	(1.0)	1.2	2
0920	(1.9)	(1.4)	4
0950		1.2	4
1020	P	0.8	4
1050	3.2	---	
1118	2.8 1.4	---	
1150	2.4 1.5	(1.0)	6
1220	3.0 1.7	1.3	6
1250	3.3 1.5	1.9	7
1320	2.6 1.1 2.0	1.4	7
1350	1.2 1.8	1.5	7
1420	1.0 2.0	1.4	7
1450	(1.0) 1.7	0.8	6
1520	(1.0) 1.9	0.2	6
1550	(1.0) 1.6	(0.5)	6
1620	(1.0) 1.7	1.1	8
1650	(1.0) 1.5	1.2	8
1720	(1.0) 1.5	1.0	8
Position	N S O S N S O S N		
Number	1 2 3 4 5 6 7 8		

Fig. P14.2 Table of ionospheric oblique echoes (Christchurch) and red arcs (Lauder) 04 September, 1959.

Captions

Fig. Pl4.1 Ionogram at Boulder 0030, 28 November, 1959.

Fig. Pl4.2 Low frequency ionogram at Boulder, 0030, 28 November, 1959.

Fig. Pl4.3 $n(h)$ profiles at Boulder under calm and red arc conditions.

Fig. Pl4.4 $n(h)$ profiles at Rarotonga during a severe storm (12/13 September, 1957) and under calm conditions (8 September, 1957).

Discussion: Topics 13 and 14 *

Discussion leader: J. R. Roach

John Roach pointed out the value of radio type measurements in understanding the storm phenomena under discussion, particularly day-time detection of ionospheric phenomena associated with SAR-arcs.

Hanson asked Warwick if he had any measurements of $\Delta n_e | n_e$ within scintillation regions. Warwick replied that published in "Radio Science" are some values which were found during quiet times, but not (so far) in SAR-arcs. 1 to 10% were typical values in quiet times. Wavelengths considered were in the vicinity of 20 km.

Cole asked Warwick what was the direction of movement observed by scintillation techniques. Warwick said that statistically, on the assumption that waves had structure which was repeatedly similar morphologically, the movement is along isoclines (lines of equal magnetic inclination), i.e. towards SE in Boulder.

Gadsden reminded us that radio aurora and aurora are not the same. He asked Warwick (1) How sure are you of the height at which irregularities occur? (2) What observational selection did you make for your statistical table showing relationship of scintillations to SAR-arcs? (3) Could not your observations be interpreted as decreases of n_e as well as increases as you have done?

Answering question 3 Warwick said he was dealing with a wave train, i.e. both increases and decreases. He stressed that the contribution of the radio technique was strongest on this question. Indeed it is "rock-solid" - but not widely accepted. As regards 2 his data were uniform over the 7 hours of observation reported. He could not be absolutely sure of the heights.

* Edited from the tape by K. D. Cole

Carleton said that (1) there were reported by Noxon irregularities in the 6300 airglow which were correlated with electron density irregularities in the ionosphere. It would be good to combine Noxon's and Warwick's techniques for observing the ionosphere. (2) It is important from the point of view of the devotees of the electric field theory of SAR-arcs to know what is the cause of the scintillations and their movement. He said that if there were an electric field present it would move any electron density irregularities with the EXB drift. It is known that electric fields in the E region can be the cause of structure there (by instability), and it would be interesting to find out if electric fields could cause structure in the F region.

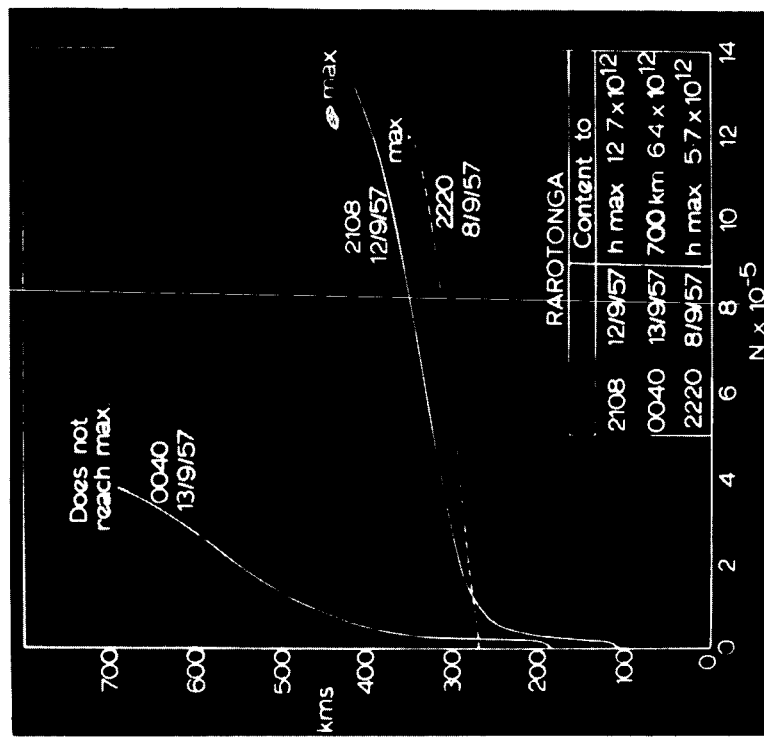
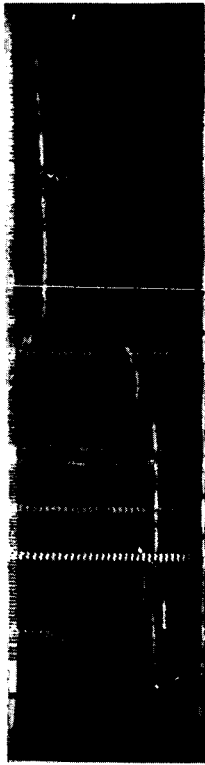
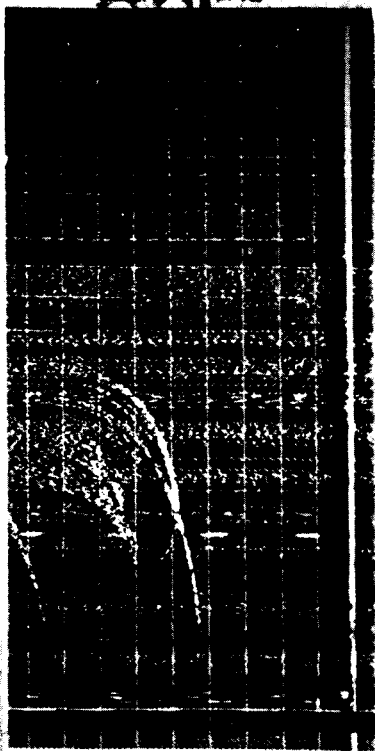
Swift suggested that in connection with electric field fluctuations in VLF range something may be observed at the ground under SAR-arcs. He suggested that instabilities may bring about thermodynamical equilibrium between, say, ring current particles and the background plasma.

King pointed out that irregularities seen on ionograms during SAR-arc conditions usually start in the F region and seldom go below 140 km altitude.

Warwick pointed out that the velocities were interpreted as phase wave velocities in the electrons, not mass motions in O atoms.

Megill commented: (1) All of these theories of two stream instability assumes equal electron and ion temperatures. In the SAR-arc the electron temperature is high and this may possibly be a triggering mechanism for instability. (2) A definitive experiment for deciding between the electric field theory of the SAR-arc and other theories which imply heating via electrons is to measure the temperature of the ions. The ion temperature in the former case should be the same as the electron temperature so that in the latter the ion temperature should be nearer the gas temperature. Henderson said that he believed the OGOC satellite will have experiments of this kind on board. John Roach said too that there will be occasions when SAR-arcs occur over Wallops Island so that rocket shots into them will be possible in the future.

Reid mentioned that random electric field, as invoked by Cole in his theory of magnetic storms, could create field-aligned irregularities. King's observations show that there is a fall of electron density within SAR-arcs so that there are strong horizontal gradients of electron density across it. Random electrostatic field by interchanging tubes of force in the presence of this gradient would cause field-aligned irregularities in the arc in the presence of these gradients.

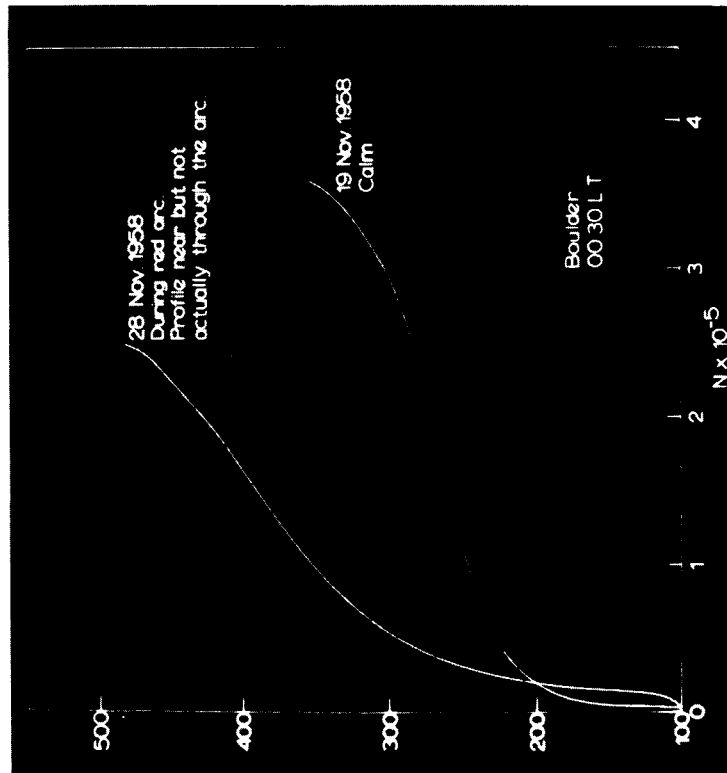


P 14.2

P 14.4

P 14.1

P 14.3



TEMPORAL AND SPATIAL VARIATIONS OF THE "KNEE" IN THE
MAGNETOSPHERIC ELECTRON DENSITY PROFILE*

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OUTLINE: An intensive study of the diurnal and magnetic-disturbance variation in the position of the "knee" has been made using whistler data recorded during the month of July 1963 at Eights Station, Antarctica. Supporting data from Byrd Station, Antarctica, and from Quebec City and Great Whale, Canada, in the conjugate region were also used. (The knee in the equatorial electron density profile is a region at several earth radii at which the number density of electrons drops rapidly by a factor of 4 or greater.)[†] The study confirmed the earlier suggestion that the knee is a permanent feature of the magnetosphere.[‡] On a moderately disturbed day (average $K_p > 3$), the diurnal variation in the geocentric distance to the knee typically shows a minimum of about $3.5 R_E$ at about 1800 LT. During prolonged quiet periods (average $K_p < 1$), the knee is frequently observed near about $7 R_E$. The inferred movements of the knee are interpreted as evidence of large-scale convective motions of the magnetospheric plasma near the position of the knee.

A number of other topics will be discussed, including the presence of low values (< 10 el/cc) of electron density in some parts of the magnetosphere, comparison of the knee to measurements of nighttime "troughs" in the ionosphere, the longitudinal scale of the knee, and the effects on the calculations of a distorted magnetic field.

Additional points made by Carpenter during the discussion were:

1. At the knee in the equatorial profile of electron density, the number of electrons drops by an order of magnitude or greater within a distance that may be less than $0.1 R_E$.
2. During periods of moderate but steady magnetic agitation ($K_p \sim 3$), the knee remains within about $1/2 R_E$ of $L = 4$ from around local midnight to about 1700 LT. The principal radial variation takes place between about 1700 LT and 0000 LT, involving a rapid outward movement near 1800 LT and a steady inward movement beginning at around 2100 LT.

* This research was supported by the National Science Foundation Office of Antarctic Programs under grant NSF GA-144 and the Atmospheric Sciences Section under grant NSF GP-1191.

[†] Carpenter, D. L., Whistler evidence of a 'knee' in the magnetospheric ionization density profile, J. Geophys. Res., 68 (6), 1675-1682, Mar. 15, 1963.

3. The movements of the thermal ionization near the knee are not known in great detail, but the period 0000LT- 0300 LT and the period near 1800 LT have been studied in some detail. It has been found that the inward movement of the knee at 0000 - 0300 LT (by about $1/2 R_E$) involves not the erosion of particles that were near the top of the knee, but an inward, compression-like convection of all the plasma near the knee.

4. At 1800 LT there appears to be a region of relatively high density plasma at a distance of from about 4 to 6 R_E . As the view of the ground receiver station changes with local time in the late afternoon, the position of the knee appears to move outward rapidly, say from 4 to 5.5 R_E in a period less than one hour. This outward movement does not involve a corresponding outward expansion of the plasma previously inside the knee. The plasma previously at $L < 4$ tends to move in a co-rotation pattern at essentially unchanged geocentric range, and the apparent outward movement of the knee is the result of the appearance of new plasma extending from the earlier position of the knee out 1 to 1.5 earth radii.

Discussion of Topic 15 *

Discussion leader: J. H. Pope

Discussion of Serbu's Density Measurements in Satellites (Fig. D15.1, p. 98)

Serbu and Maier measured thermal electron and proton densities and energies by means of retarding potential analysers flown on Imp A and B. They deduce electron density as a function of distance to about 6 earth's radii. The density decreases with distance as $\frac{1}{R^{3.4}}$ and is

about a factor of ten higher than that obtained from whistlers. Electron energies are about 0.3 ev at 2 earth's radii to above 2 ev at 7 - 8 earth's radii.

Discussion about whether solar wind induced field distortions could produce 'knee' effect.

In determining density, dipole field is assumed as well as a density distribution model. The time delay integral is, of course, weighted in favor of the electron geomagnetic frequency and plasma frequency near the top of the path and hence could be effected by magnetic field distortions. However, such effects are small and nose whistler method tends to average out effects produced by non-dipole condition.

* Edited from the tape by J. H. Pope

One test is to study the total electron content along the path eliminating the necessity to assume a density distribution function. The change in the electron content is as much as a factor of 10 across knee region compared with 20 - 30 for the electron density in equatorial plane. The knee effect is so large that it must imply a real decrease in electron density beyond the knee.

Discussion pertaining to whether density inside knee is increased in addition to decrease outside knee.

In general, increase in density inside knee is not seen although effects of great storms have not yet been studied. The increase, if present at all, is not more than 10 - 20%. The data do not indicate a pumping of particle across knee.

Discussion pertaining to increase in particle energy at and beyond knee.

Whistlers are sensitive to temperature because of cyclotron absorption effects. Data sometimes show good propagation inside knee with poor propagation outside, indicating a thermal gradient at knee. Gurnett has observed increase in particles of greater than 10 kev and bursts of VLF noise at latitudes corresponding to the knee position. Also OGO obtains similar increase of VLF activity.

Discussion pertaining to possibility that ionospheric trough might be associated with knee.

Electron densities measured on Alouette at about 1000 km indicates a depression, or trough, at latitudes corresponding to $L = 2.4$ to 4 on the night side. However, if the knee is mapped down the field lines to ionospheric heights, the effect would be sharper than the observed trough. Also, the trough disappears on the day side while the knee only moves to greater distances. Thus while the two effects might be related, they are loosely coupled.

Caption

Fig. D15.1 Electron density distribution observed by Serbu and Maier using the retarded potential analyser on Imp-A. (see page 98).

EQUATORIAL AIRGLOW

W. Steiger

Summary

Observations have been made at Haleakala, Hawaii since 1961 in $\lambda\lambda$ 5577, 6300, and 5893 in the zenith and also scanning over the entire sky. The results, some of which are shown in figures P16.1 to P16.5, show that the 6300 emission is usually enhanced to the south of Hawaii, and at times sporadic enhancements an order of magnitude or more above the background occur within the circle of observation, sometimes including the zenith. The enhancements sometimes take on a very fine structure with bright "fingers" * coming up from the south, as on Sept. 11/12, 1961, and shown in figure P16.4, or a rather structureless band running roughly east-west as on Oct. 10/11, 1961, and shown in figure P16.5.

The 5577A emission generally appears quite uncorrelated to the 6300, as seen in figure P16.6. But during the bright 6300 enhancements the 5577 frequently shows a similar enhancement superposed on an uncorrelated background, as in figure P16.7. This suggests that the 5577A emission arises from two different levels in the atmosphere. The lower level is presumably at around 100 km, as has previously been found at higher latitudes, and gives rise to the uncorrelated component. The higher level we suggest coincides with the height of the 6300A emission, at around 250 to 300 km, and gives rise to the correlated component. A schematic diagram illustrating this concept is shown in figure P16.8. As determined from a number of such enhancements, it appears that the ratio of 5577 to 6300A emission in the upper level is about 1 to 5.

The isophote maps frequently show the isophotes to be rather aligned, as for example in figure P16.5. An analysis of the alignment of isophotes during the hours 2155 to 0255 showed a significant fraction of the maps show an aligned character, and of these the predominant direction of alignment is along the isoclines, as shown in figure P16.9.

A search for a correlation of the 6300 intensity with geomagnetic activity failed to show any, as shown in figure P16.10. Even when a seasonal effect was removed from the 6300 data, no effect was found.

Figures

Fig. P16.1 6300A zenith observations showing typical night-time variations. Top: a night which is considered "quiescent" in the zenith. Middle and bottoms: nights which are considered "active" with enhancements occurring. (Calculated curve is from Barbier's formula)

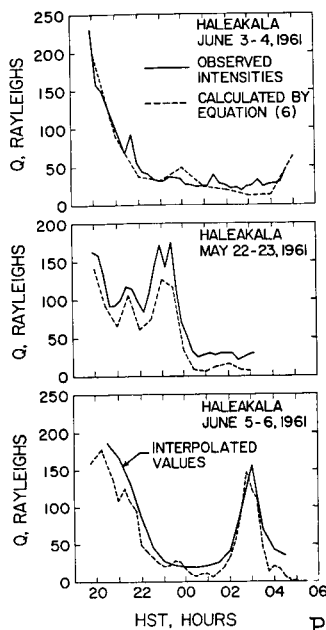
* Called TOAE by VanZandt (see pages 6,105)

- Fig. Pl6.2 The night of Sept. 11/12, 1961, which is an especially good example of an active night with two enhancements.
- Fig. Pl6.3 A series of 6300A isophote maps of the sky showing both quiescent and enhanced conditions.
- Fig. Pl6.4 An isophote map of the sky at 6300A for the night of Sept. 11/12, 1961, during the first enhancement. Note the large gradients and finger-like structure.
- Fig. Pl6.5 An isophote map of the sky at 6300A for the night of Oct. 10/11, 1961. This is also an enhanced night but lacking the great structure of Sept. 11/12, 1961. In this case the enhancement has the form of an east-west band.
- Fig. Pl6.6 5577A and 6300A variations during the night of Sept. 5/6, 1961. The two colors are generally quite uncorrelated.
- Fig. Pl6.7 5577A and 6300A variations during the active night of Sept. 11/12, 1961. The 5577A emission shows enhancements correlated with the 6300A enhancements.
- Fig. Pl6.8 A schematic diagram illustrating the concept of a two-layer theory of the 5577A emission. The ratio of 5577 to 6300A emission in the upper layer is taken as about 1 to 5 as measured on a number of nights.
- Fig. Pl6.9 Number of midnight alignments in each 10° interval of azimuth, and azimuth of horizontal component of geomagnetic field.
- Fig. Pl6.10 Average 6300A intensities versus planetary magnetic index, K_p , showing one year's data.
- Paper 18 Theory of Equatorial 6300 - V. L. Peterson
This paper made use of Figure Pl6.2 of paper 16.
- Paper 17 Equatorial Ionosphere - G. A. M. King
This paper made use of Figures Pl6.2, Pl6.4, and Pl6.5 of paper 16, and in addition the two figures labeled Pl6.11 and Pl6.12.
- Fig. Pl6.11 Illustrating the fact that when the ionosphere has large tilt and curvature, the "overhead" ionosonde echo does not truly come from overhead and the multiple comes from yet another point.

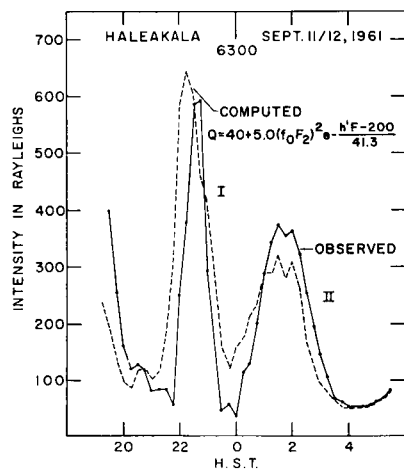
Fig. P16.12 The Maui ionograms of Sept. 11, 1961 and Oct. 10, 1961.

Discussion

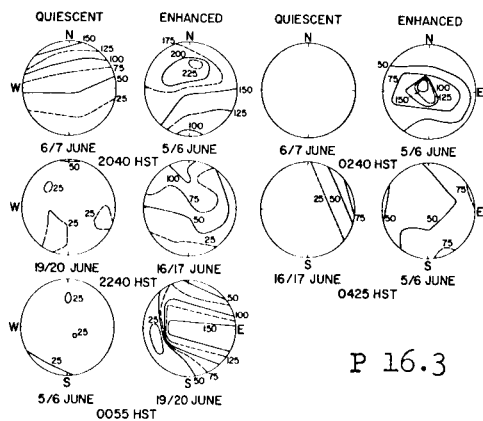
Fig. P16.13 5577A on the night of Sept. 11/12, 1961, showing a computed curve based on the empirical equation shown.



P 16.1

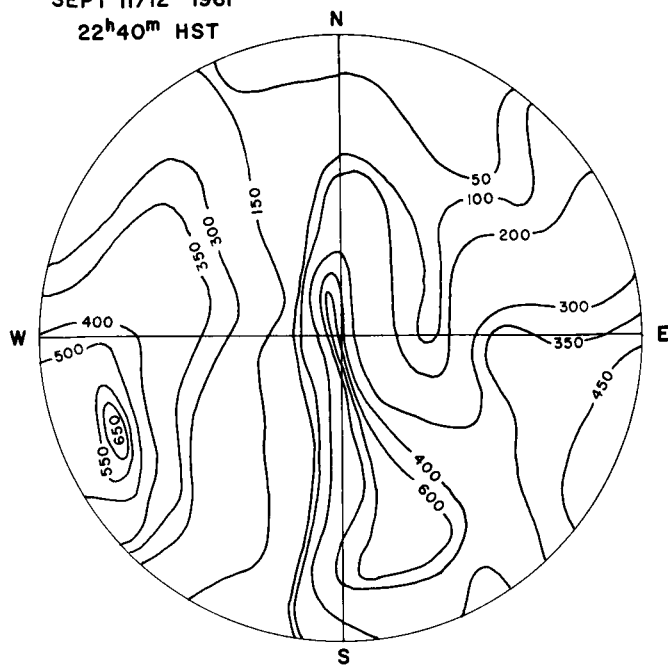


P 16.2



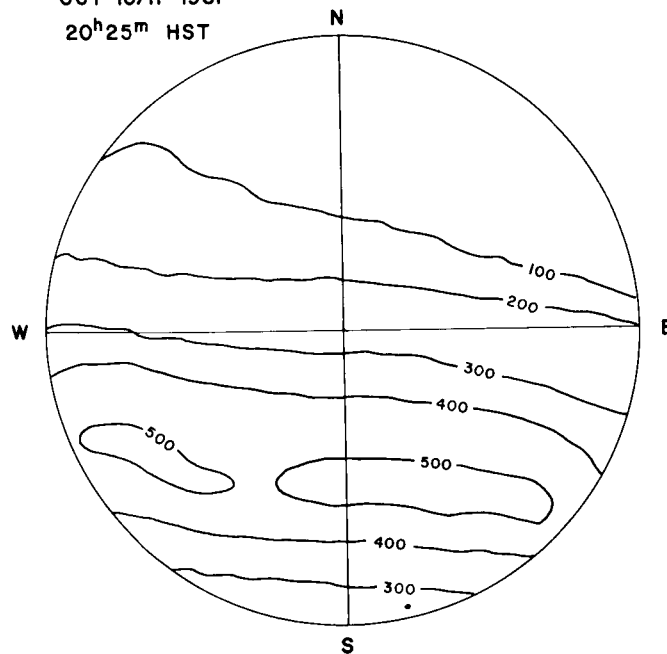
P 16.3

SEPT 11/12 1961
22^h40^m HST

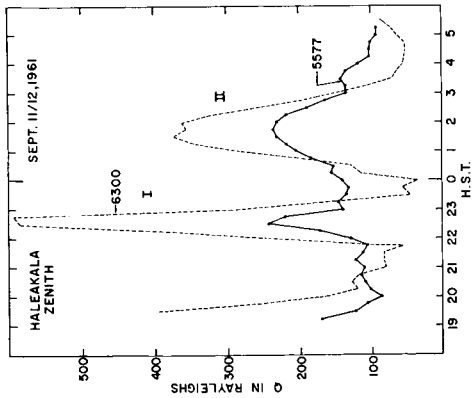


P 16.4

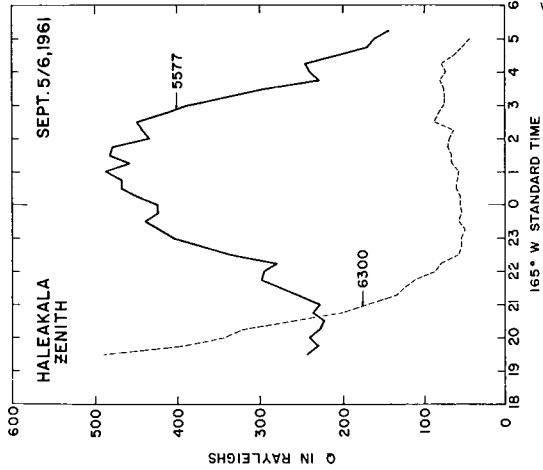
OCT 10/11 1961
20^h25^m HST



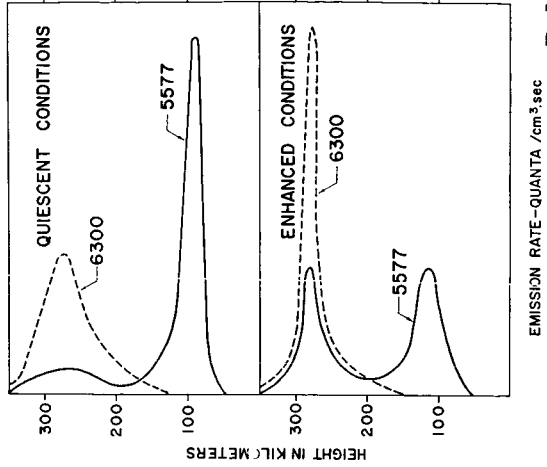
P 16.5



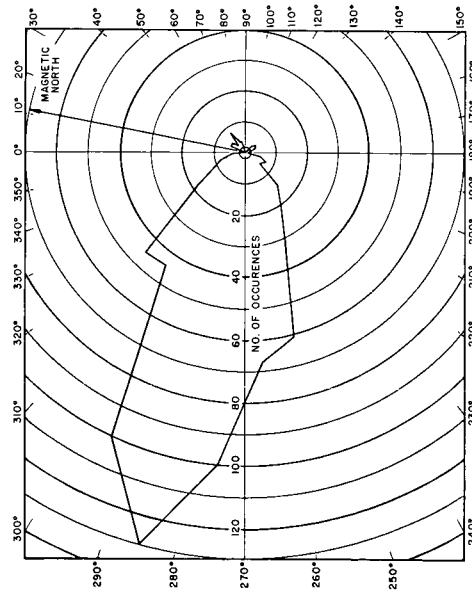
P 16.6



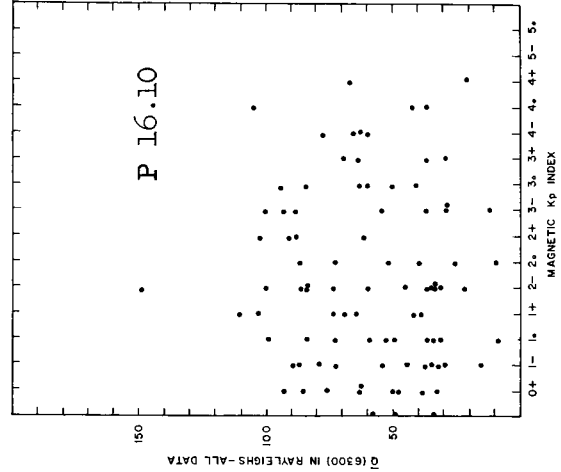
P 16.7



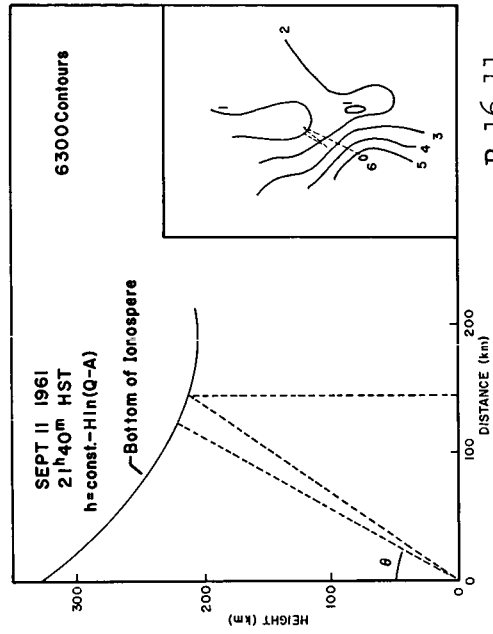
P 16.8



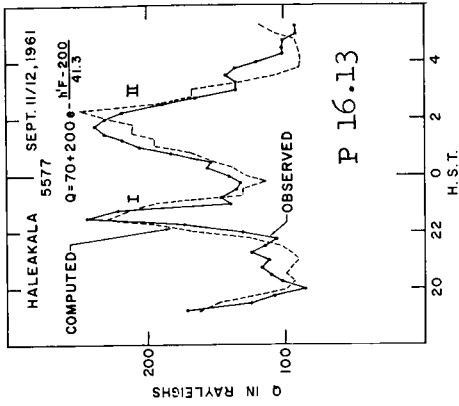
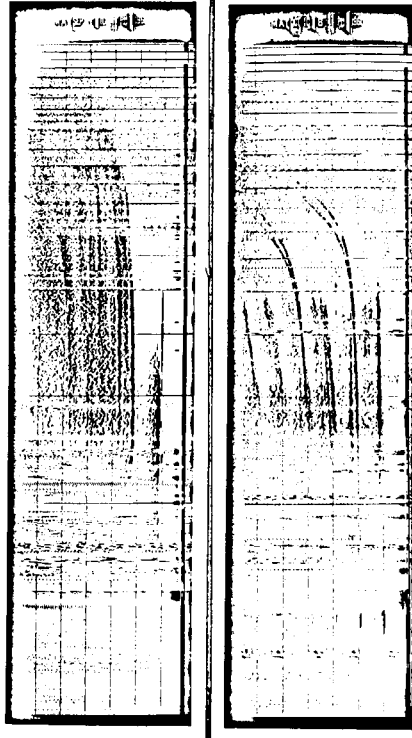
P 16.9



P 16.10

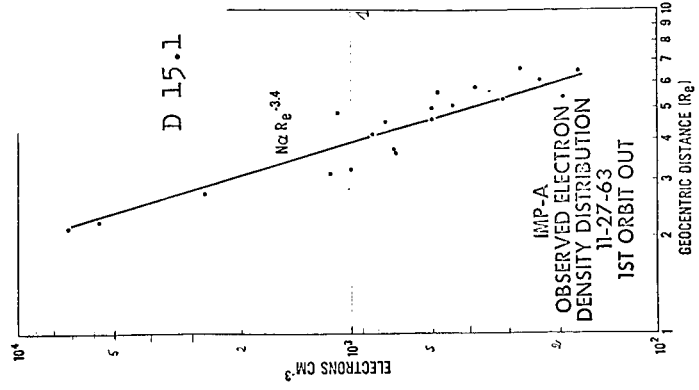
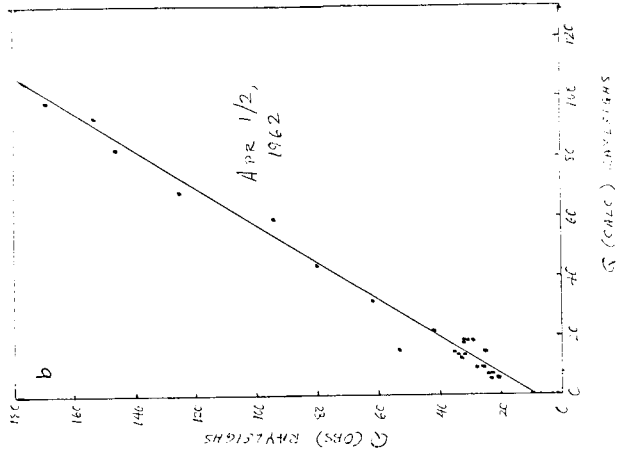
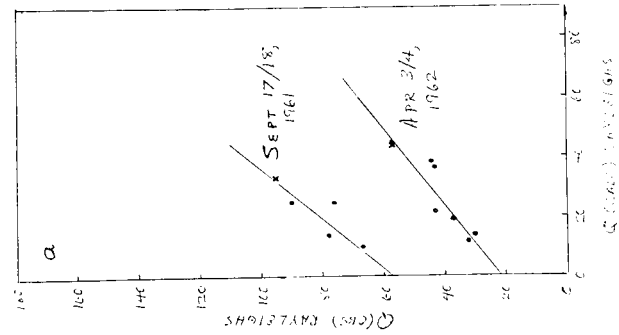


P 16.11



↓ P 18.1

↑ P 16.12



THE EQUATORIAL IONOSPHERE

G. A. M. King
DSIR
New Zealand

This paper describes the relation between ionospheric features and 6300 photometric plots at low latitudes, the success of the Barbier formula and different kinds of alignment found in the structure. Ionospheric observations at Maui and Rarotonga strongly suggest that phenomena are similar at conjugate points.

Captions for 'Equatorial Ionosphere' slides

Fig. P17.1 6300 circle plot at Maui 22h 45m, 11 September, 1961.

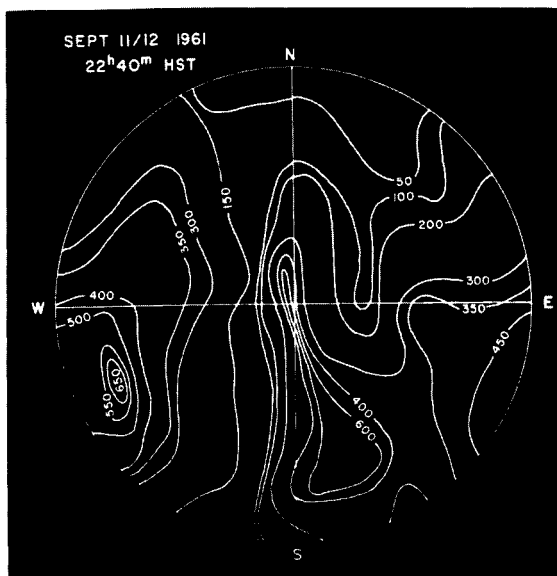
Fig. P17.2 Ionograms at Maui (a) 22h 45m, 11 September, 1961.

(b) 20h 25m, 10 October, 1961.

Fig. P17.3 6300 circle plot at Maui 20h 25m, 10 October, 1961.

Fig. P17.4 Part of 6300 circle plot and geometry for bottom of the ionosphere deduced from it, 21h 40m, 11 September, 1961.

Fig. P17.5 Comparison of observed 6300 and that calculated from Barbier formula, 11/12 September, 1961. Print to be supplied by Dr. Steiger.

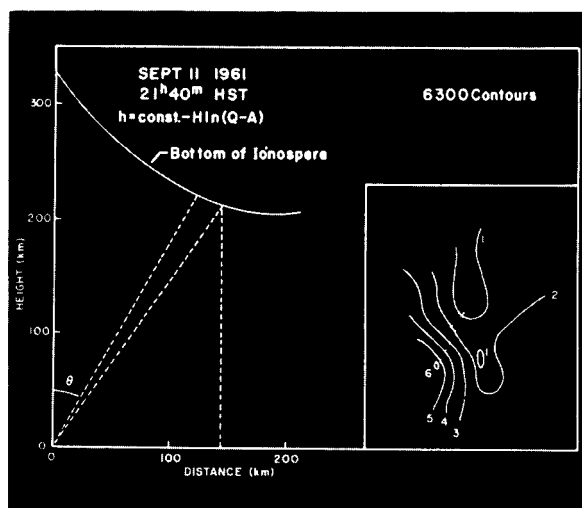
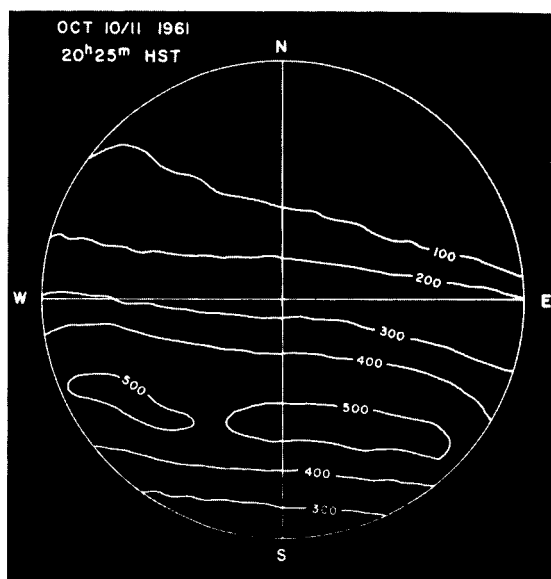
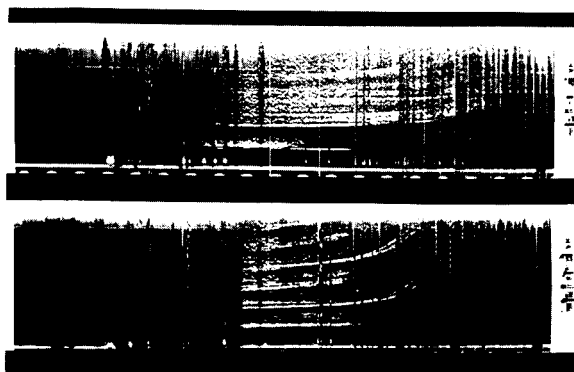


P 17.1

P 17.2

P 17.3

P 17.4



TOPIC 18

THEORY OF LOW LATITUDE $\lambda 6300$ NIGHTGLOW AND ITS APPLICATION TO ANALYSIS OF $N_e(h)$ AND NIGHTGLOW DATA

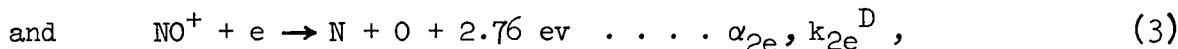
Vern L. Peterson

Although the mechanism for producing the SAR-arc is not well understood, that which produces the normal $\lambda 6300$ nightglow, particularly at the lower latitudes, is on firmer ground. This is not to say, however, that the normal $\lambda 6300$ nightglow is completely understood, for as we shall see it seems to have two components, only one of which is explained by the theory outlined below.

Because the $\lambda 6300$ nightglow arises from the $^1D_2 \rightarrow ^3P_2$ transition, its emissivity is merely

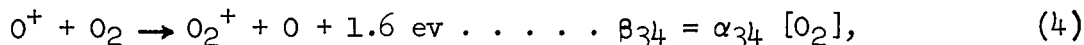
$$\epsilon_{6300} = A_{6300} [O(^1D)], \quad (1)$$

where A_{6300} is the Einstein coefficient for the transition. We need to know, therefore, the height distribution of $O(^1D)$. Normally, the predominant process for producing $O(^1D)$ at night and at low latitudes is dissociative recombination. These electron loss reactions, which dominate in the F-region,



are energetically capable of producing $O(^1D)$, although spin conservation severely limits the amount of it produced by (3), as pointed out by Dalgarno and Walker in 1964. Further, (2) is also capable of producing $O(^1S)$, which in turn yields $O(^1D)$ upon radiating a $\lambda 5577$ photon. The specific reaction rates are given by the α 's, and the excitation probabilities by the k 's. The D and S superscripts refer to the 1D and 1S states. The subscript notation is: $O_2^+ = 1$, $NO^+ = 2$, $O^+ = 3$, $O_2 = 4$, $N_2 = 5$, and electron = e.

The O_2^+ and NO^+ are produced primarily by



The continuity equations for $[O(^1D)]$, $[O(^1S)]$, $[O_2^+]$, and $[NO^+]$ can be set up on the basis of these reactions and from the fact that the $O(^1D)$ and $O(^1S)$ states are deactivated by collisions and by radiative transitions. It can be shown that the motion terms in the four continuity equations can be safely ignored and that probably only a minor error will

result in assuming quasi-equilibrium for these four constituents. The resulting forms of the continuity equations, when combined with the expression for charge neutrality

$$N_e = [O^+] + [O_2^+] + [NO^+],$$

lead to an emissivity of

$$\epsilon_{6300} = 0.76 \frac{a + b X(h)}{1 + d_{DP}(h)/.0091} \cdot \frac{\alpha_{2e}(h)\beta_{35}(h)N_e^2(h)}{\alpha_{2e}(h)N_e(h) + \beta_{35}(h)[1 + \alpha_{2e}(h)\beta_{34}(h)/\alpha_{1e}(h)\beta_{35}(h)]}, \quad (6)$$

where $a \equiv k_2^D e \leq 1,$ (7)

$$b \equiv k_1^D e + 0.94 k_{1e}^S \leq 2, \quad (8)$$

$$X \equiv \beta_{34} / \beta_{35}, \quad (9)$$

and d_{DP} is the collisional deactivation coefficient for the $O(^1D)$. For purposes of numerical evaluation, α_{2e} is assumed to have a height dependence given by

$$\alpha_{2e}(h) = \alpha_{2e}(300) T(300)/T(h), \quad (10)$$

and O_2 and N_2 are taken to be in diffusive equilibrium so that

$$\beta_{3i}(h) = \beta_{3i}(300) \frac{T(300)}{T(h)} e^{-Z_i(h)} \quad (11)$$

where i is 4 or 5 and where

$$Z_i(h) = \int_{300}^h \frac{dh}{H_i}, \quad (12)$$

where H_i is the pressure scale height of the i^{th} constituent. Also, the term in brackets in (6) has been replaced by $[1 + X(h)/3X(200)]$, since rocket observations indicate that $\alpha_{2e}\beta_{34}/\alpha_{1e}\beta_{35} \approx 1/3$ at 200 km. Finally, the collisional deactivation coefficient, d_{DP} , has been taken to be roughly equal to $2 \times 10^{-11} [O_2]$, although collisions with particles other than O_2 have also been included.

Equation (6) has been numerically integrated for a variety of values of a , b , $X(300)$, $\alpha_{2e}(300)$, and $\beta_{35}(300)$, using as data $N_e(h)$ profiles

deduced from ionograms, $T(h)$ profiles taken from model atmospheres of Harris and Priester, and a $d_{pp}(h)$ profile calculated as mentioned above. Figure 1 illustrates a sample comparison of such calculations with observations from Maui, Hawaii, for reasonable values of the unknown parameters. Simultaneous nightglow observations and ionosonde recordings were examined and the best of these used.* If we assume that a background component is present for each set of observations, then the agreement between the calculated and observed intensities is very good. The value of this background component, Q_{back} , is easily obtained by extrapolating the set of points back to $Q_{calc} = 0$ (which corresponds to no ionosphere), as indicated in the figure. The fact that the points for a given set cluster very closely about a straight line indicates that neither the background component nor the ionospheric parameters $\beta_{35}(300)$ and $X(300)$ varied significantly during the period of observation. The ratio $X(300)$ would not be expected to vary much during the night, but $\beta_{35}(300)$ and Q_{back} might. It is conceivable that a variation in $\beta_{35}(300)$ is just balanced by a variation in Q_{back} , but this seems unlikely.

It can easily be demonstrated that the value deduced for Q_{back} for a given night is very insensitive to our choice of parameters [a , b , $X(300)$, $\alpha_{2e}(300)$, and $\beta_{35}(300)$], or to errors in the atmospheric model data [$T(h)$ and $d_{pp}(h)$], or to errors in observation [$N_e(h)$]. A 20% calibration error in the photometric observations will, of course, produce a 20% error in the value of Q_{back} deduced.

Because the variations in the $\lambda 6300$ nightglow are explained very well by the theory as due to corresponding variations in the density, shape, and height of the F-layer, the product $[a + bX(300)] \beta_{35}(300)$ can be deduced from the observations. This product is normally found to lie in the range $1 - 3 \times 10^{-5} \text{ sec}^{-1}$. Because $\beta_{35}(300)$ is probably on the order of 10^{-4} sec^{-1} , or larger, this implies that $a + bX(300)$ is 0.1 or smaller. This not only agrees with the assertion of Dalgarno and Walker that $a \approx 0$ but also implies that $b \approx .1$, since $X(300)$ is probably on the order of unity. That is to say, not only is reaction (3) inefficient in producing $O(^1D)$, but reaction (2) is also. If we consider all the possible sources of error in the estimate of $[a + bX(300)] \beta_{35}(300)$, we conclude that the value quoted above is probably correct to within about a factor of three.

It is of interest to note that the second term on the right in Barbier's semi-empirical formula,

$$Q = A + B(foF2)^2 e^{-(h'F - 200)/H}, \quad (13)$$

*For the benefit of those workers who may wish to make similar comparisons, I should remark that a normal nighttime ionogram usually cannot be reduced to a reliable $N_e(h)$ profile. I estimate that only 1 or 2% of the nighttime Maui ionograms that I have examined are of such nature as to yield a good $N_e(h)$ profile.

is obtained simply by integrating a simplified form of (6). Barbier's additive term, A, identifies quite closely with the background component, Q_{back} , discussed above. Figure Pl6.2 from the preceding paper of Steiger illustrates how well Barbier's equation fits the observations. Note that the equation seems to anticipate the rise to the first maximum during the night. This discrepancy is explained by King (see Topic 17).

Finally, an expression similar to (6) has been derived for the emissivity of $\lambda 5577$ from the F-region. The ratio of emissivities can be shown to be

$$\frac{\epsilon_{6300}}{\epsilon_{5577}} = \frac{0.81}{1 + d_{\text{DP}}/.0091} \left(0.94 + \frac{k_{1e}^D}{k_{1e}^S} + \frac{k_{2e}^D}{k_{1e}^S} \frac{1}{X} \right). \quad (14)$$

During a large tropical enhancement of $\lambda 6300$, there is also an enhancement of $\lambda 5577$, as expected. From the almucantor sweep records in $\lambda 6300$ and $\lambda 5577$, it is possible to measure the ratio of red to green for the F-region emissions. A preliminary estimate of this ratio is 3.3 (standard deviation of .5). Setting this equal to $\epsilon_{6300}/\epsilon_{5577}$ then gives $k_{1e}^D/k_{1e}^S = 3.1$, if we take $k_{2e}^D = 0$ and ignore collisional deactivation.

Caption

Fig. Pl8.1 A comparison of the calculated and observed intensities of the $\lambda 6300$ nightglow for Maui, Hawaii. The intercept at $Q(\text{calc}) = 0$ represents the background component that is not explained by the theory discussed in the text. (See page 98).

Discussion of Topics 16, 17, 18

Discussion Leader: T. E. VanZandt

VanZandt said that equatorial enhancements of the red emissions of atomic oxygen are important in two ways: (1) The part of the emission which is correlated with the ionosphere provides a kind of map of the F layer over a 1000 km radius. (2) The uncorrelated part may be a clue to another excitation mechanism. The airglow maps show extreme spatial variations indicating the presence of a strong force on the F-layer plasma. Two possibilities suggest themselves; a complicated wind structure or a complicated electric field structure. Observations at other longitudes and in the southern hemisphere are required, particularly in conjugate regions. Another important question is how the total content varies along tubes of force involved in the enhancements.

VanZandt said that data from Jicamarca show that in one period of two hours the F layer moved downward 200 km and $1\frac{1}{2}$ hours later $\frac{2}{3}$ of the content was eaten away. This would have produced about 250 R of red line emission.

VanZandt also said that we may anticipate an increase of the 6300 emission during sunspot maximum, for densities of almost 10^7 cm^{-3} have been observed at such times. Rees asked if there were 6300 observations from Huancayo. VanZandt said yes. Roach said there was a plan to put a photometer in at San Juan, Argentina (gm lat 20° S).

Cole asked (i) How do the irregularities in luminosity move and with what speeds? (ii) Is there a preferred direction of tilt of the bottom of the F region of the ionosphere, and (iii) At what latitude does conjugacy peter out?

VanZandt suggested that the movement was extremely slow. On 11-12 September 1961 there were two enhancements which suggested movements of 100-200 km in a few hours. Roach confirmed that the movements were slow and irregular. There could be disappearance and reappearance of enhancement. Roach suggested it appeared to be more an in situ phenomenon than a motion phenomenon.

King said that on Oct. 10-11 when there was a uniform band of luminosity from E to W the tilt would have been to lower heights toward the equator. During TOAES (Tropical oxygen airglow enhancements) (a term coined by T. VanZandt M.D.) the tilt could be in almost any direction. (Sometimes the toes turn up! Laughter)

Walker commented on the constant in the Barbier formula, suggesting that it might be accounted for by including deactivation. Peterson said his theory has deactivation in it already.

McElroy asked if 5577 also correlated with the Barbier formula. VanZandt said the observations show that the contribution of 5577 by recombination was proportioned to that of 6300.

Gadsden asked how much OH continuation was in the 6300 background measurements. Steiger said OH could possibly account for the background (the constant in the Barbier formula)

Roach, commenting on A in the Barbier formula, said that any number of mechanisms may contribute to it. Carleton said, the number of processes is not large and it would be interesting to find out what causes it. He asked if the Barbier formula worked well at Fritz Peak. Peterson said it works better at lower latitudes than middle latitudes. Carleton said this suggests that there is also another mechanism. VanZandt said that since intensities were lower at mid-latitudes and taking into account calibration errors one should not expect as good a fit there.

King said that Sam Neff at Christchurch used the Barbier formula with success for large changes of intensity of 6300. But it is very hard to relate the height to virtual height because of the presence of E region ionization and this makes the Barbier formula unworkable, when the variations of 6300 are small.

Romick asked, do you ever see an enhancement of I (5577) without one in I (6300)? Steiger answered no.

McElroy asked what other emissions are observed in the tropics, e.g. 3914 A^0 . Roach said they could not give a good spectroscopic answer.

Bowles said in relationship to enhancements (at least as regards ionization) there were consistent motions at the equator (Jicamarca, Peru) toward the west at about 150 m/sec. At Arecibo (Puerto Rico) which is at the same geographic latitude as Maui, large irregularities are seen to move. Why don't they show up in your airglow measurements?

VanZandt said that Maui was significantly south (geomagnetically) of Arecibo and usually the enhancements seen at Maui are to the South anyhow so that direct comparison is not possible. Bowles said that at the equator the drift was given by $E \times B$. VanZandt said that drifts of TOAES were clearly slower than the drifts in small scale irregularities at the equator observed by backscatter techniques.

Gadsden commented again on the Barbier formula. Bearing in mind the possible contamination from OH, was the "constant" in a Barbier's formula constant throughout a night, and did it differ from night to night? Are there any measurements say of Na lines which matches in any way the variability of this "constant"? Steiger replied that this was a good suggestion but they have not looked for it. It was the opinion of Peterson that some of it could be produced in this way, but probably not all, particularly when this background component is as large as 50 or 100 R.

Greenspan mentioned that simultaneous ionosonde and photometric observations are being made along the coast of Chile. For 6300 they measure two bands, one at 6200 and one at about 6300 and subtract the two to get the line emission at 6300. This may give some information about the OH and also for testing the Barbier formula in mid-latitude.

Walker suggested that the background component could be caused by a poor choice of the collisional deactivation coefficient. Peterson answered that this had been investigated and it was found that increasing d_{pp} by an order of magnitude had little effect on Q_{back} .

Walker argued that physical significance should not be attributed to the additive constant in the Barbier formula and suggested that the nightglow red line intensities might be fitted as well with the formula

$$I = \frac{A \exp\left(\frac{-h^1}{H}\right)}{1 + B \exp\left(\frac{-h^1}{H}\right)}$$

This formula reflects the high deactivation coefficient indicated by the dayglow observations.

LeRoi Smith in reply to a question, said they found a maximum in I (6300) near gm. lat 15° S (on a boat doing a NS transit). Roach pointed out that Barbier found the equatorial I (6300) symmetrical with respect to gm. equator and Japanese scientists on the "Soya" observed the maximum in the vicinity of 15° S. This is very definitely a magnetically controlled phenomenon and one cannot be sure to call it airglow. Rees pointed out that the variability of the A in Barbier's formula may be attributable to calibrations errors which can change from night to night.

VanZandt closed the discussion for lack of time pointing out that λ 5199 observations are desirable.

TOPIC 19

SATELLITE OBSERVATIONS OF THE AIRGLOW

E. P. Ney

No abstract available

Ney presented wide band observations, of the airglow layer near 100 km altitude. The observations were made from a satellite orbiting at an altitude of 1000 km.

There was a high positive correlation of brightness every 8 orbits and a high anti-correlation every 4 orbits. He also showed and discussed pictures of the airglow layer (near 100 km) taken by astronaut Cooper.

Discussion of Topic 19

Discussion leader: M. H. Rees

Rees said that the value of 2 Rayleighs per angstrom agreed well with the value for the intensity of airglow continuum in common use.

Walker asked how Ney measured the value of $1.6 \text{ R per } \text{\AA}^0$. Ney said they were inferred zenith intensities from the "side-on" thickness of the airglow layer found from astronaut Cooper's pictures.

Henderson asked how rapidly Ney scanned the airglow layer through each telescope. Ney said the period of the scan was 35 minutes, but they got data points every 0.3 seconds.

Rees asked about the redness of color of the airglow pictures and Ney explained. Someone asked where the stars were on the airglow picture. Ney explained that in Cooper's earlier pictures stars were visible but the window got dirtier during the night. Cole asked what was this dirt on the window of the space craft. Ney said it was presumably "junk that condensed during the night; I don't know". They were not even prepared to admit that there was dirt there, but it was a fact that the sensitivity of the film was known and also the airglow brightness and the transmission decreased during the flight.

Roach pointed out that the airglow reported by Ney was from about 100 km altitude whereas that of the 6300 discussed in topics 16, 17, 18 was at altitudes above about 250 km.

The meeting was closed by Dr. F. E. Roach.

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